

**Herb Nelson** 





# **Objective of the Course**

Provide an update on the sensors, methods, and status of the classification of military munitions using geophysical methods

- Advanced processing of data collected with existing commercial instruments
- Significant improvements possible using advanced EMI sensors

Advances in Classification - Introduction

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Report (SAR)

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#### **Presenters**

- Dr. Steve Billings (Sky Research)
- Dr. Thomas Bell (SAIC)
- Dr. Dean Keiswetter (SAIC)

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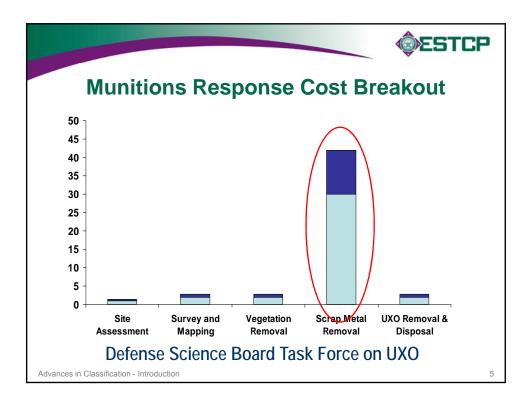


### **The Munitions Problem**

- There are over 3,000 sites suspected of contamination with military munitions
- They comprise 10s of millions of acres
- The current annual cleanup effort is on the order of 1% of the projected total cost
- To make real progress on this problem, we need a better approach

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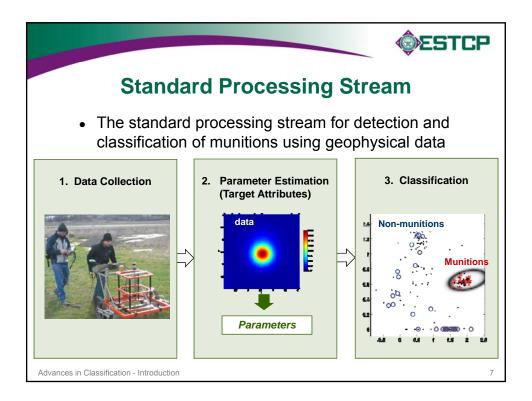


#### Classification

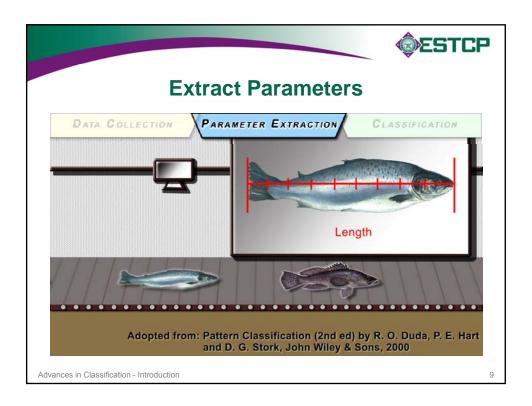
- Classification offers the chance to divide anomalies into those caused by targets-of-interest and those caused by other things
- Recognize that current field methods involve implicit discrimination
  - Mag & Flag instrument sensitivity setting and human interpretation
  - ♦ Digital Geophysics threshold selection; what is a target?
- Our goal is a principled, data-based approach to classify targets as either "non-hazardous" or "targets of interest"

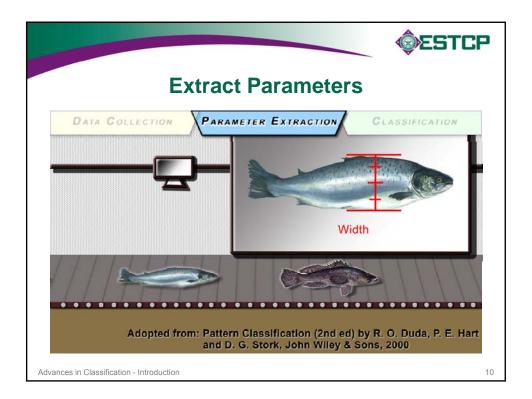
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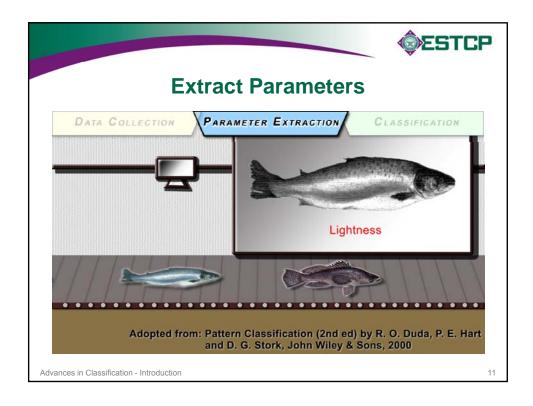
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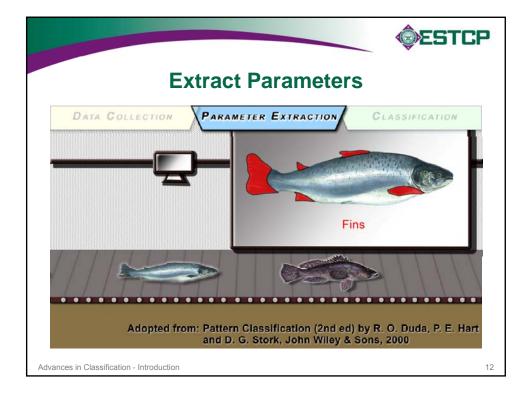


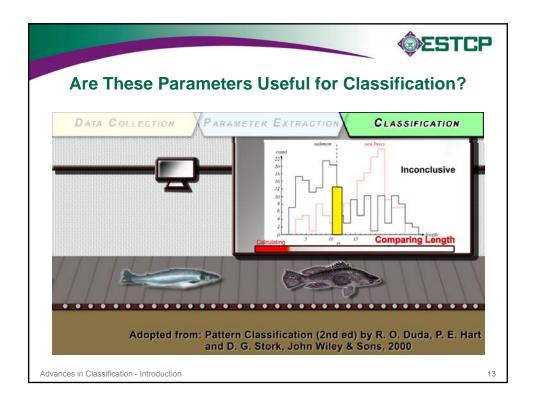


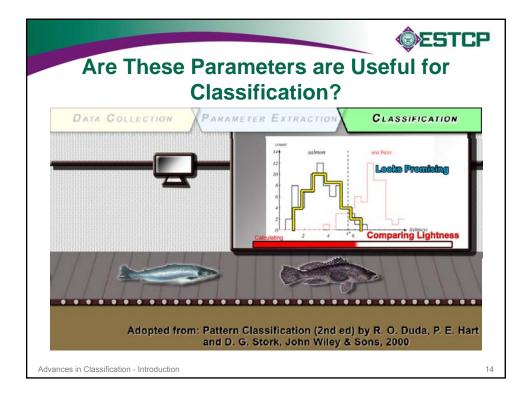




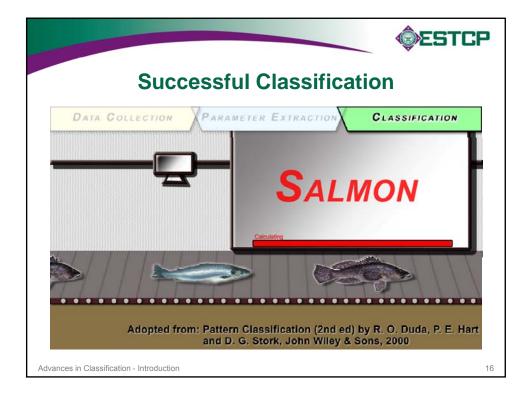


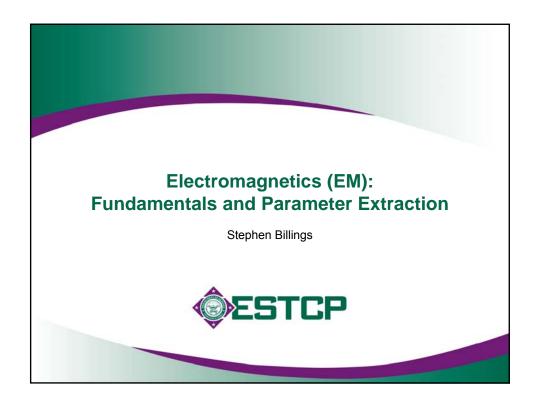












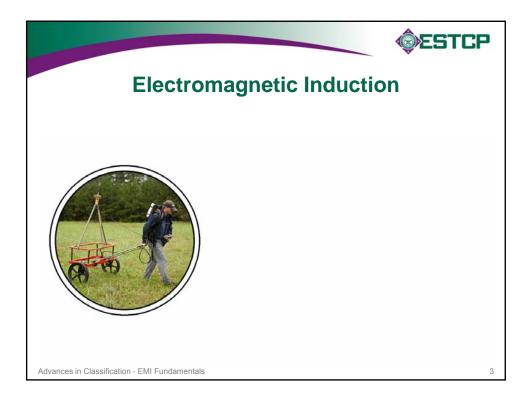


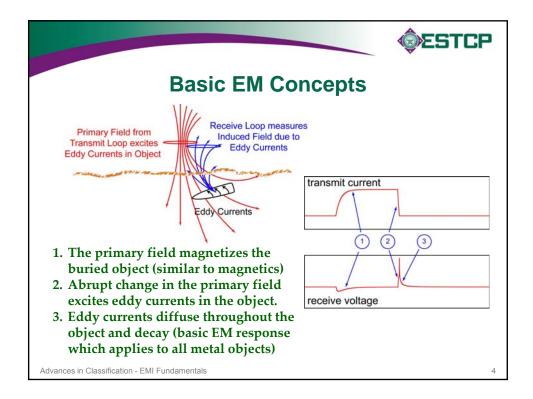
#### **EM Module Outline**

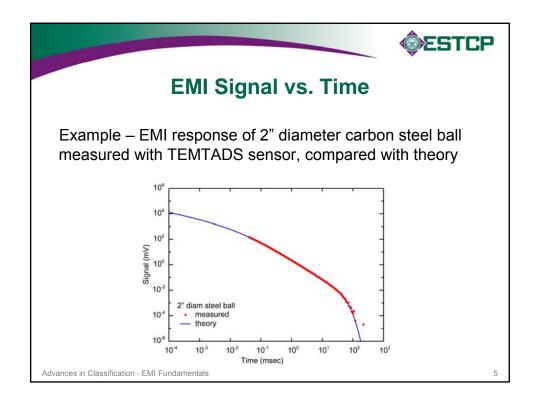
- EMI Fundamentals
  - ♦ How EMI sensors work and what they measure
  - ♦ Principal axis polarizabilities
- Data collection
  - ♦ Survey and mapping
  - ◆ Target illumination
- Parameter extraction
  - ♦ Dipole inversion to determine principal axis polarizabilities

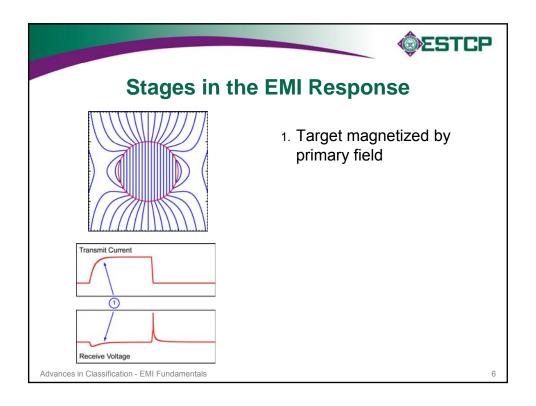
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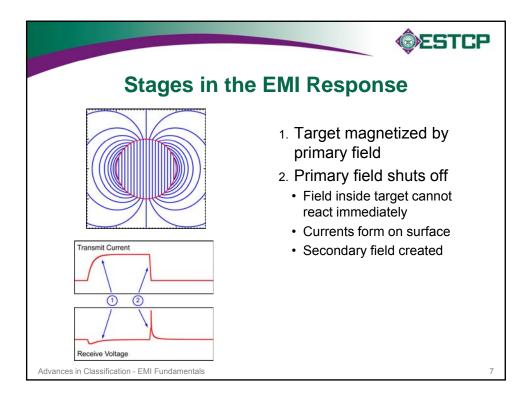
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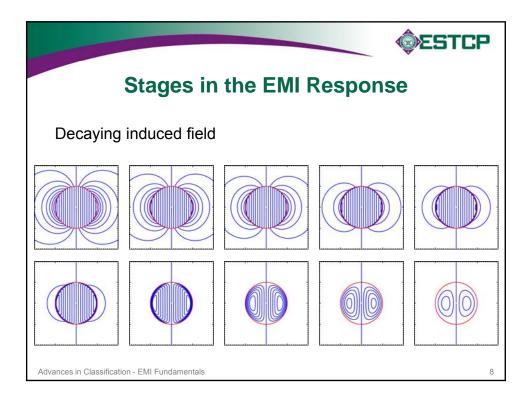


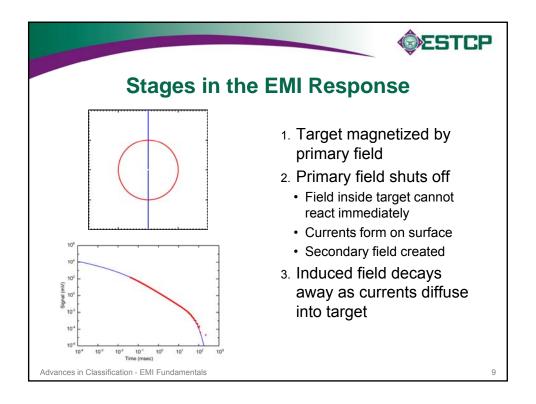


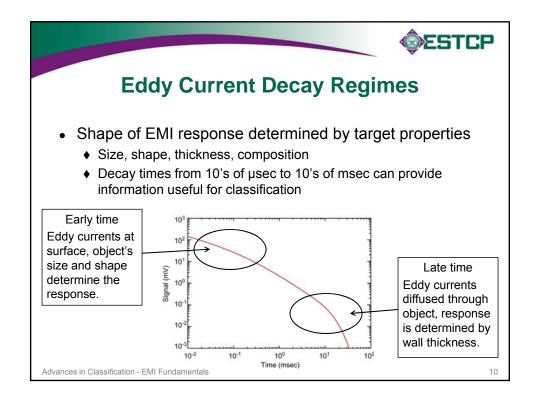


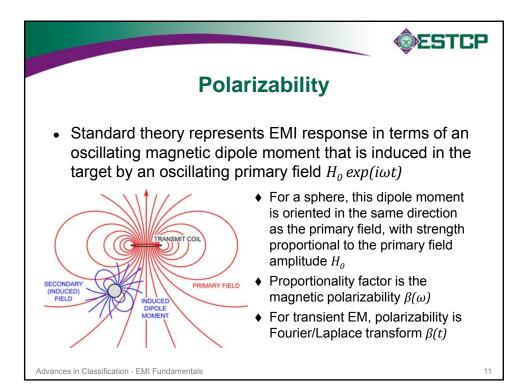


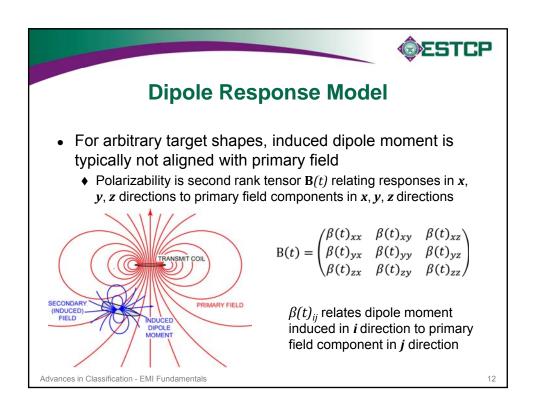


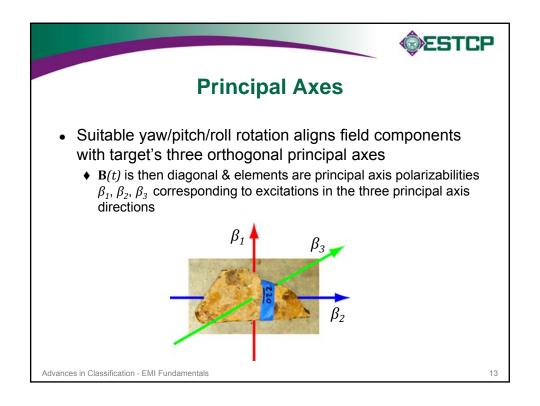


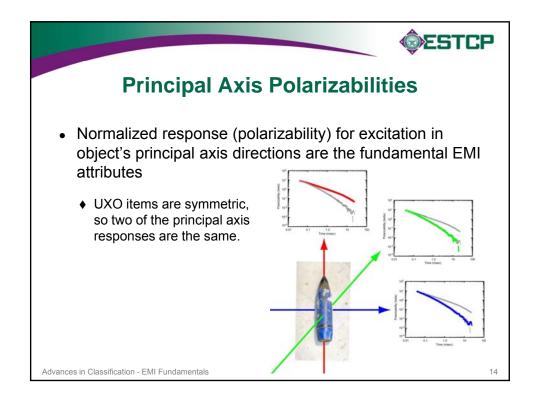


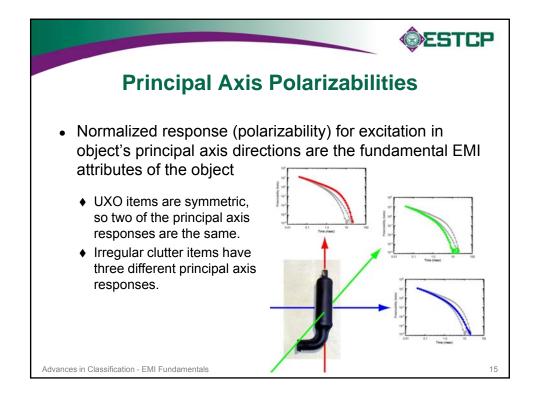


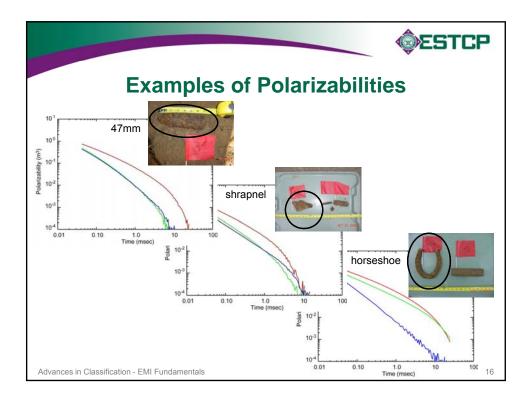


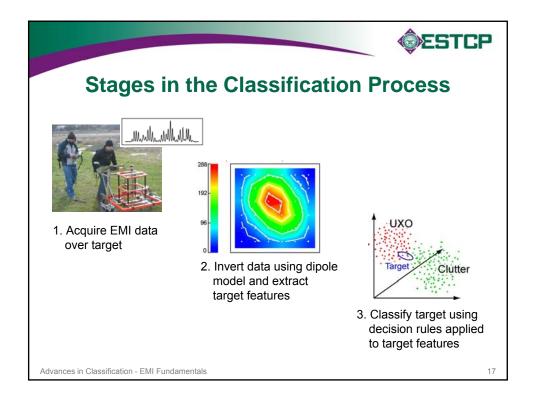


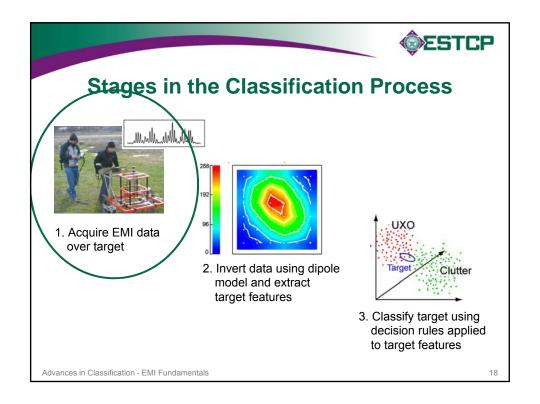


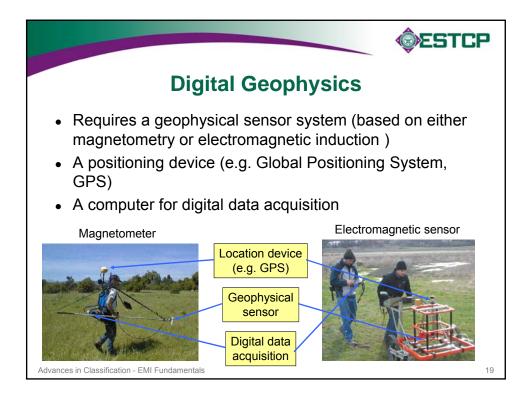


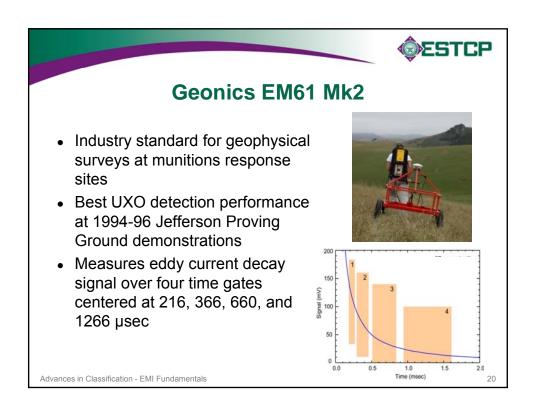


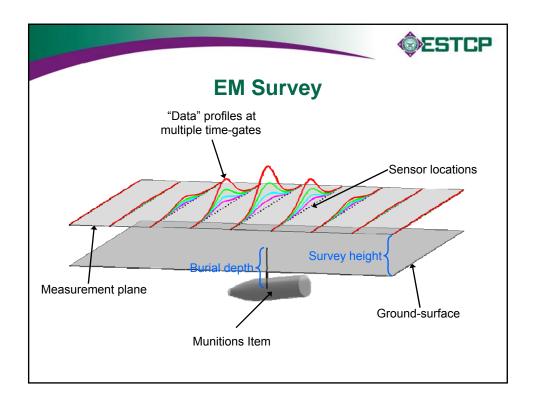


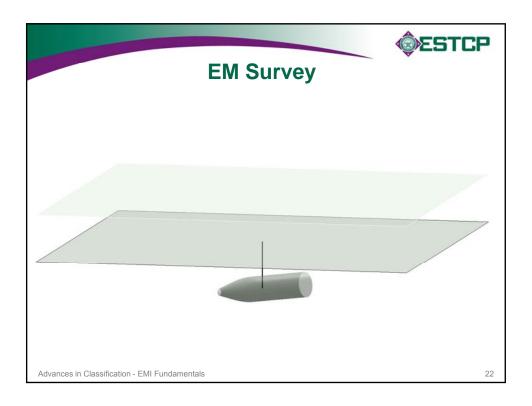


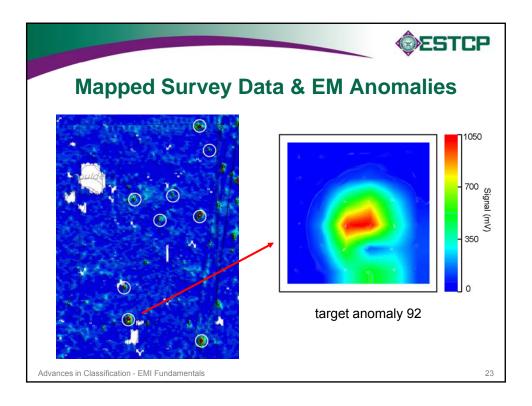


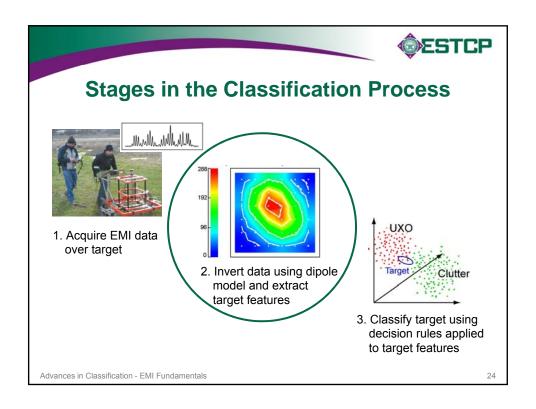


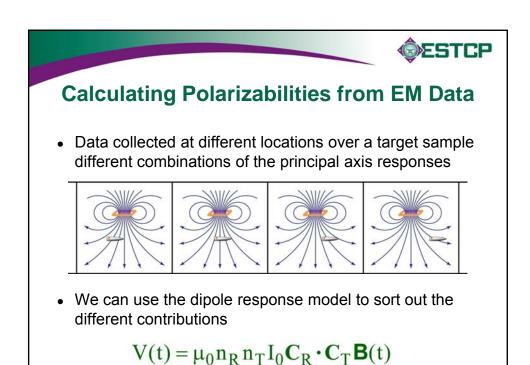




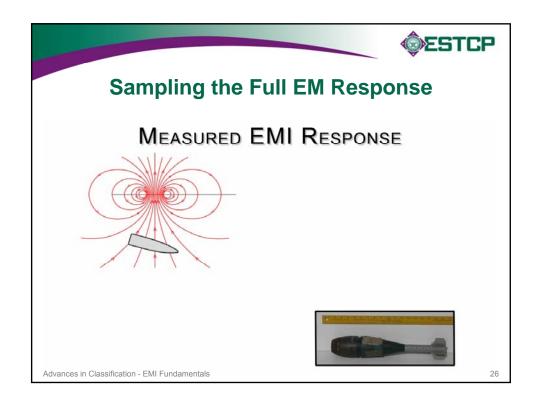


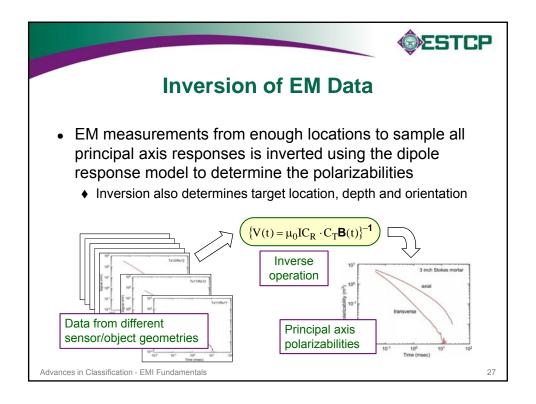


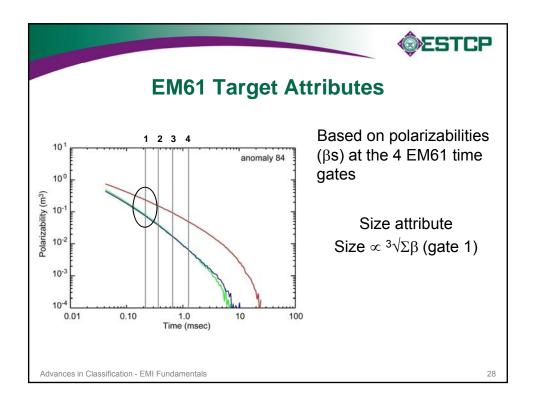


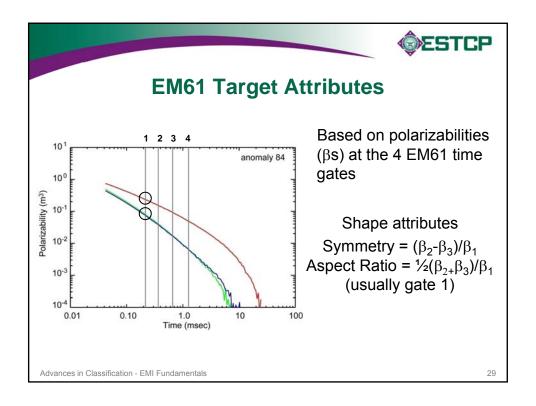


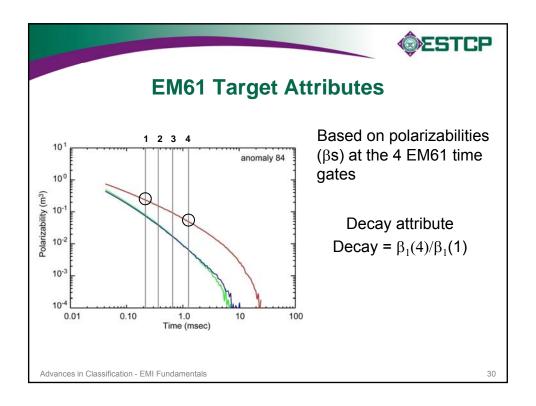
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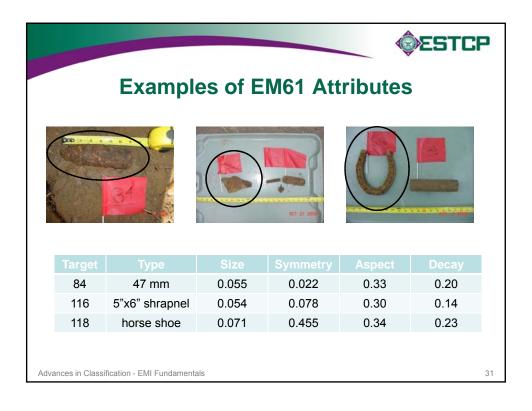


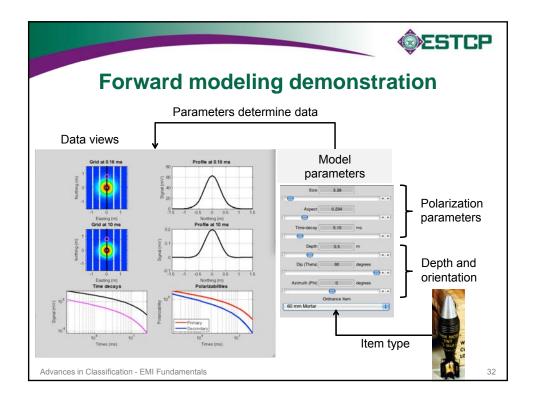


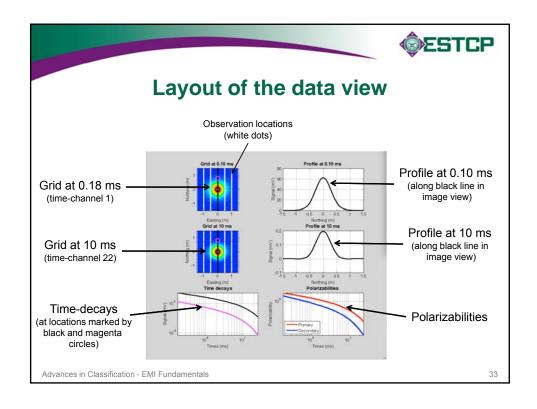


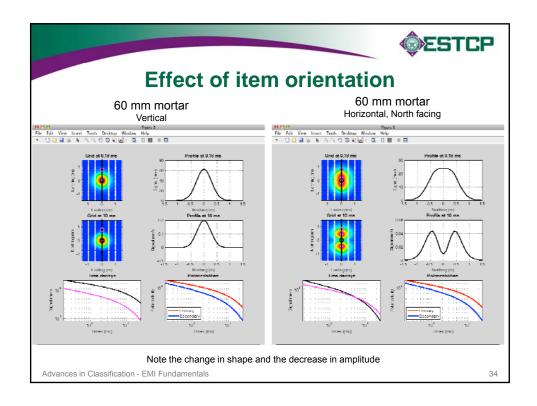


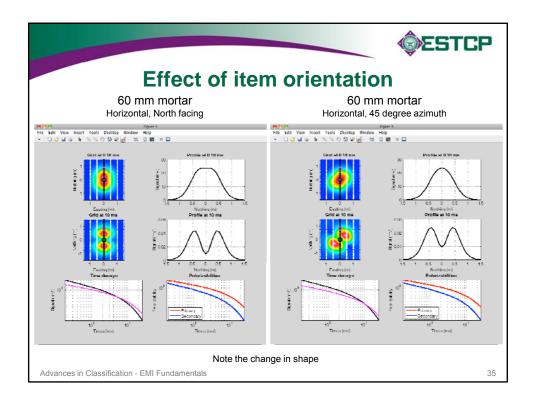


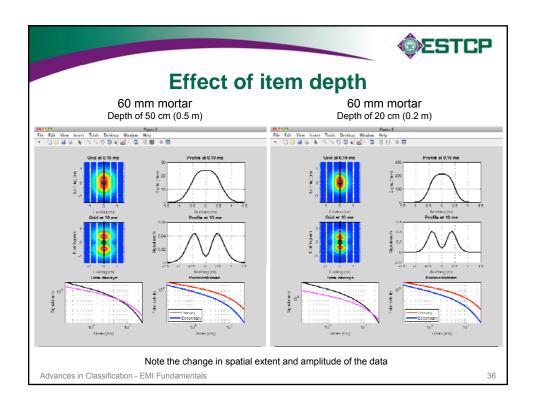


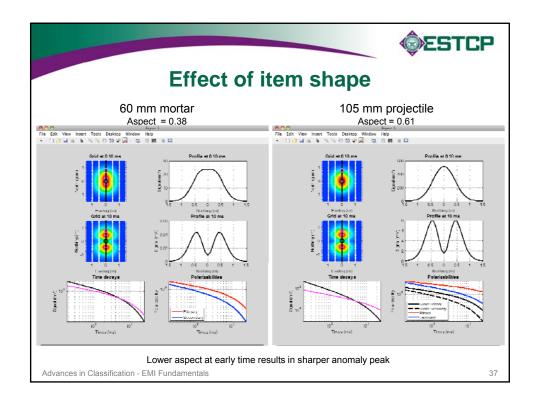


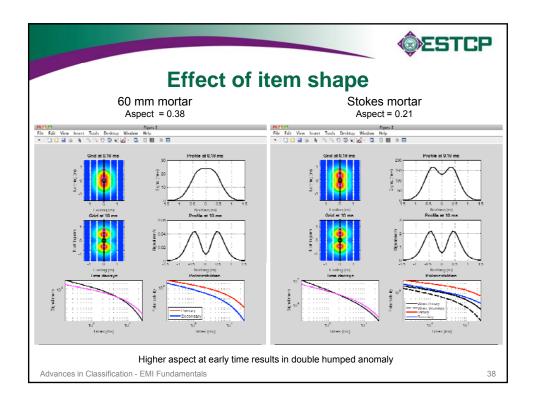


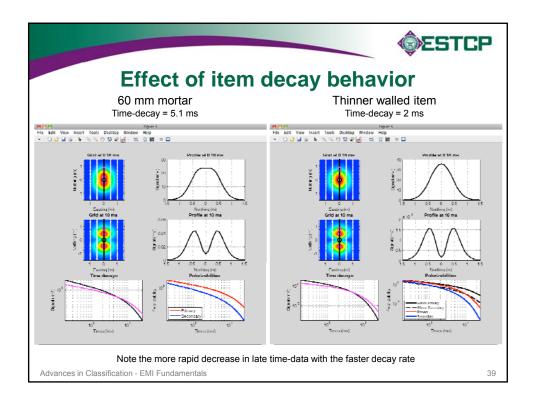


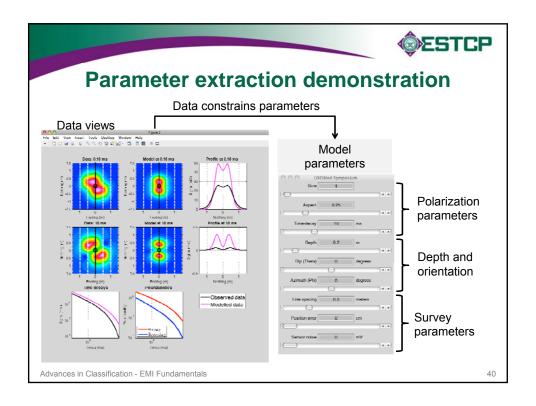


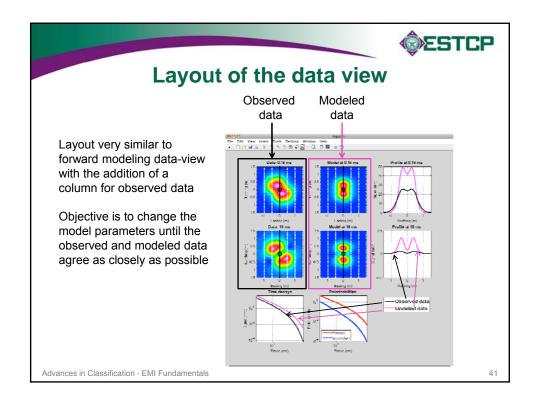


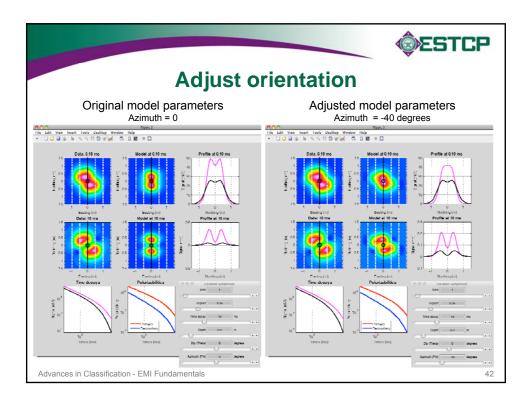


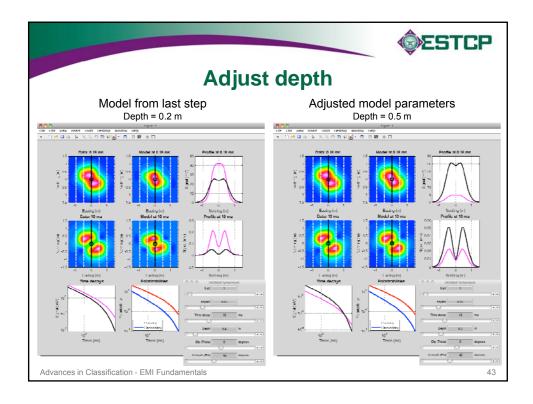


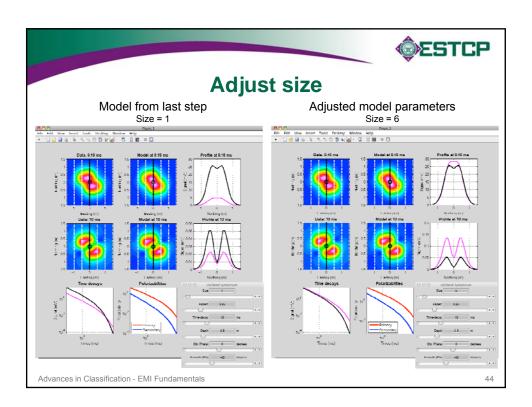


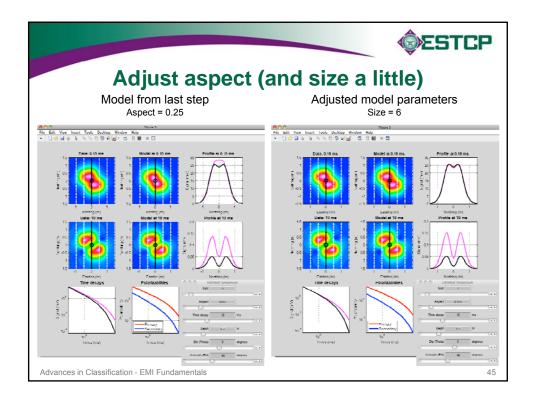


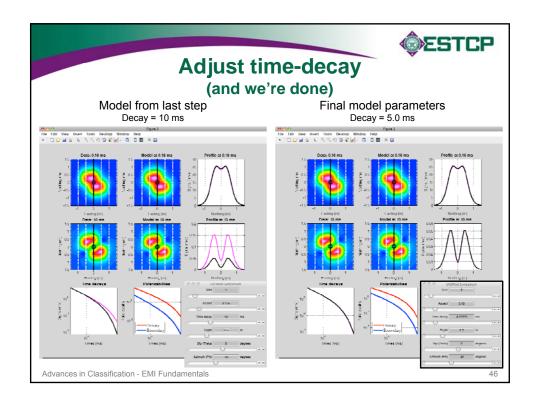


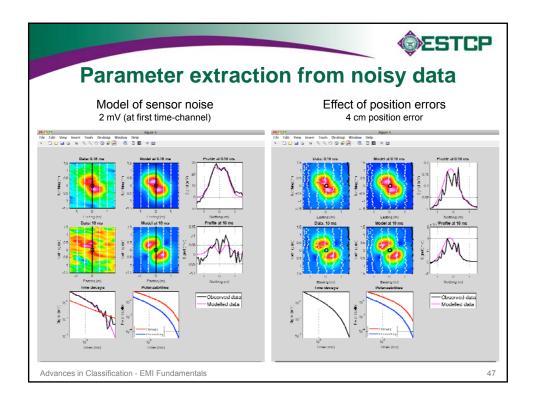


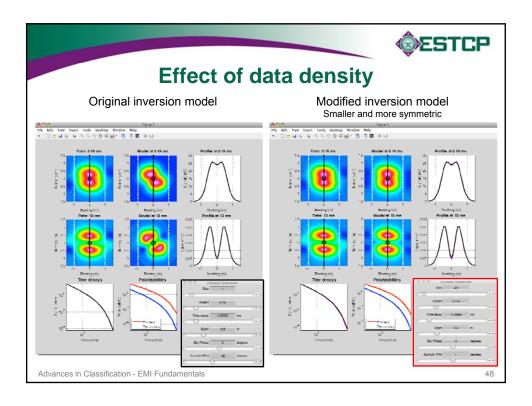












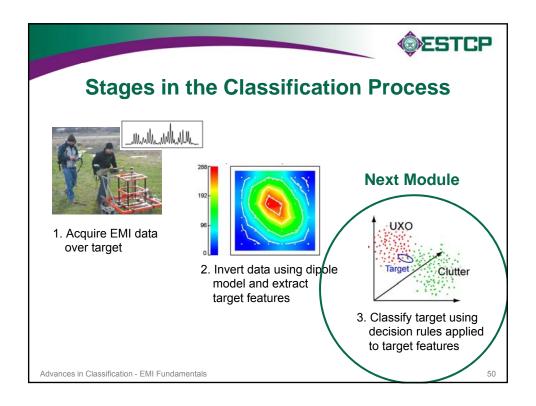


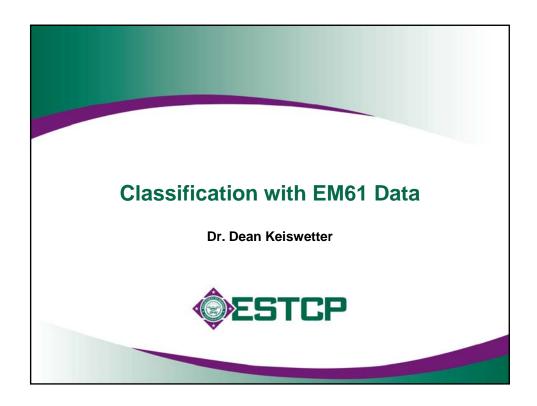
# **Summary**

- EMI sensor data holds information about target's size, shape, thickness and material composition
- Polarizabilities along target's principal axis directions fully characterize EMI response
  - ♦ Basis for classification
- Target's principal axis polarizabilities are determined by mathematically inverting EMI data collected over target
  - Requires excitation of target and observation of response from many directions
  - Ability to constrain polarization tensor parameters depends on quality, density and diversity of collected data

Advances in Classification - EMI Fundamentals

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#### **Outline**

- Classification Process
  - ♦ Methods
  - ♦ Product
  - ♦ Assessment
- EM61 Datasets
  - Elements of a database
  - ♦ Analysis environment & flow
  - ♦ Noise issues & problems
  - ◆ Data requirement summary
  - ♦ Example #1: Aberdeen Proving Ground
  - ♦ Example #1: San Luis Obispo
- Concluding comments

Advances in Classification - Classification with EM61 Data



# **Classification Objective**

We want...

- (a) to identify those anomalies that are definitely clutter (they cannot possibly be UXO) at the site
- (b) a principled process that results in a decision

This entire process is not magic...it must make sense, be physically inspired, and be documented



Advances in Classification - Classification with EM61 Data

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# How do we classify?



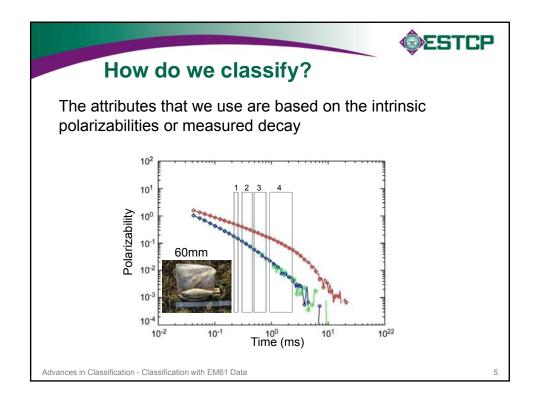
Visually, we use physical attributes such as size & shape

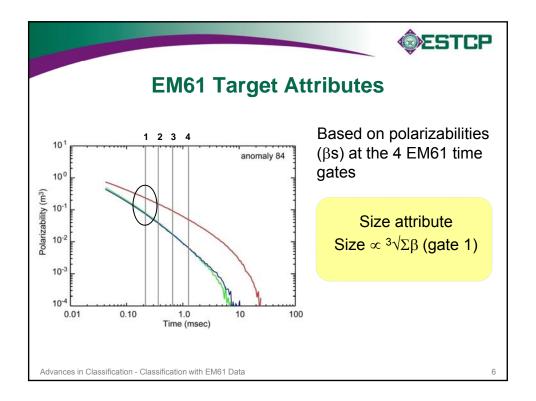


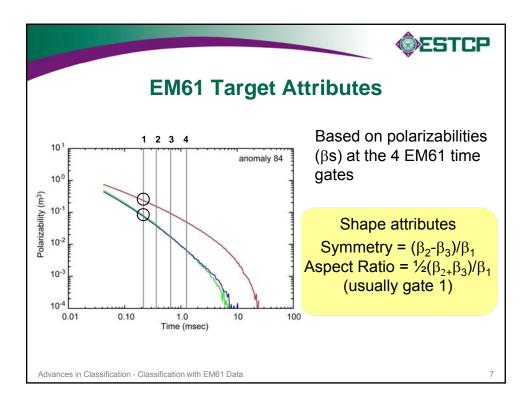
Because we cannot see buried objects, we must rely on attributes determined from geophysical data

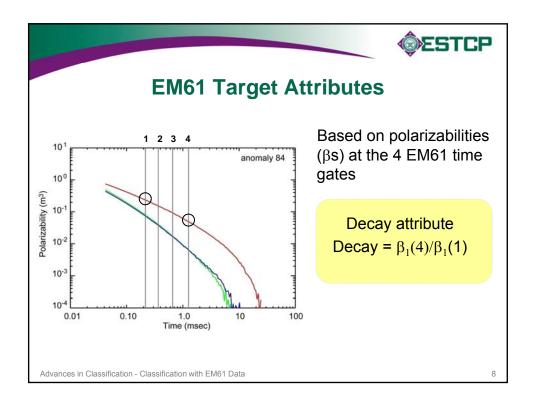
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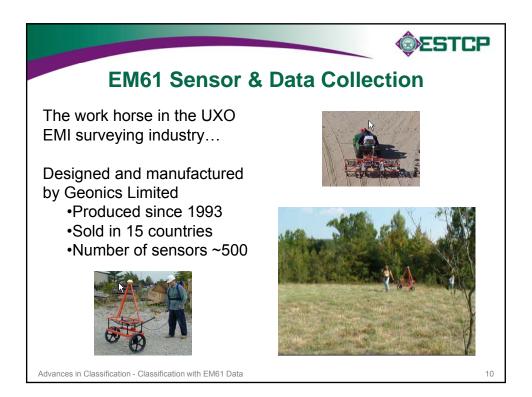


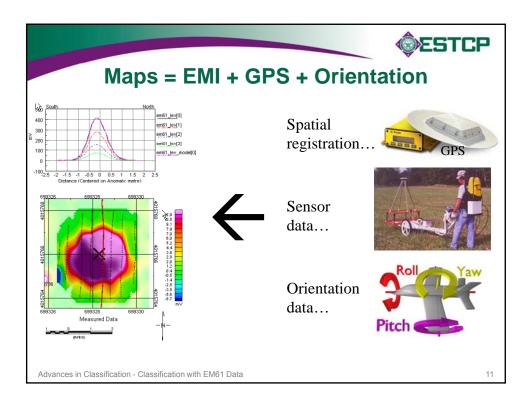


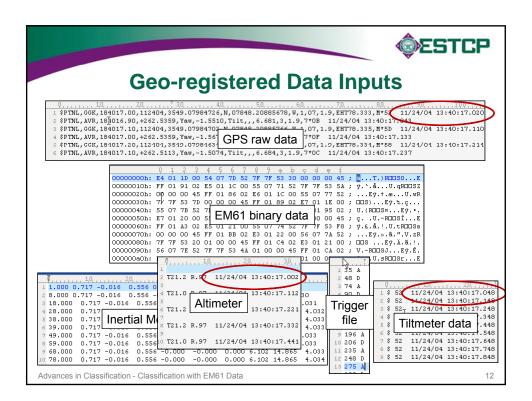


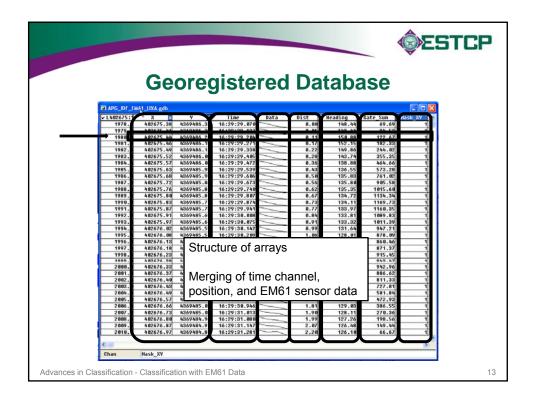


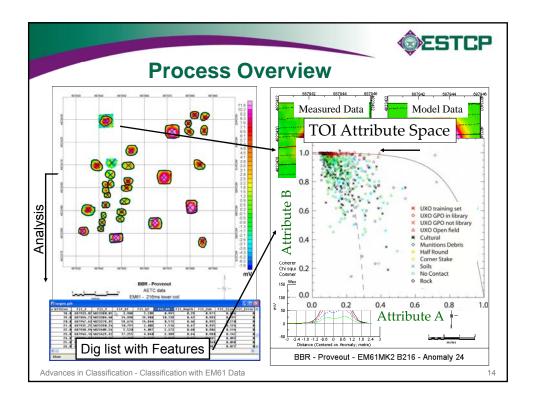
### ESTCP **Classification Cartoon** Given attributes for a site with a 10.00 single munitions item **General Process:** 1) Visualize attributes Attribute TOI 'space' 2) Obtain labels (e.g., ground truth information) Non-TOI 'space' 3) Establish boundaries -0.10 this is the classification piece It can be this easy...if the Attribute 1 0.00 0.05 0.15 0.20 features are separable Remember the goal: identify anomalies that are not UXO Advances in Classification - Classification with EM61 Data



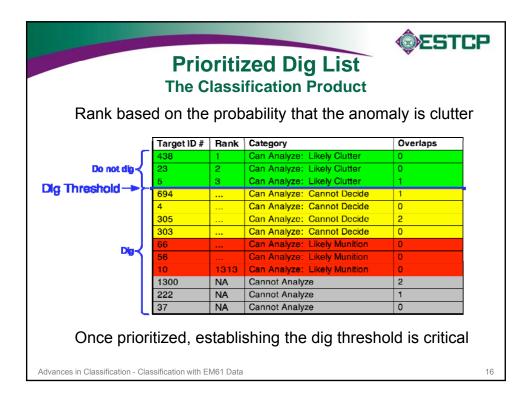


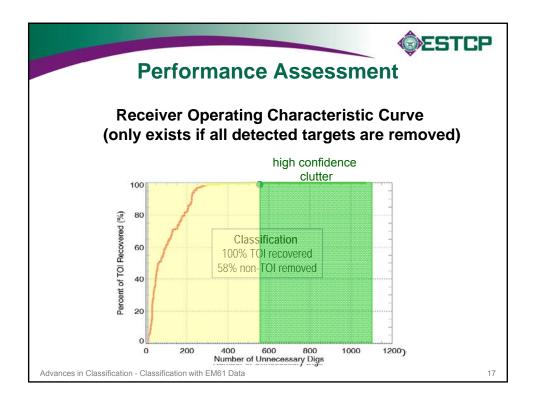


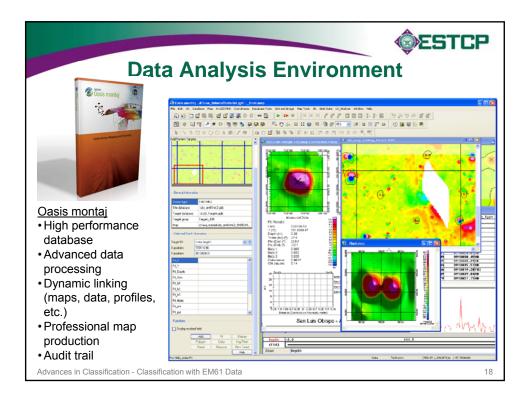




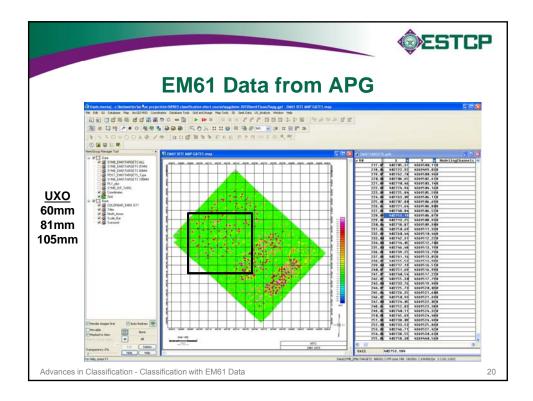


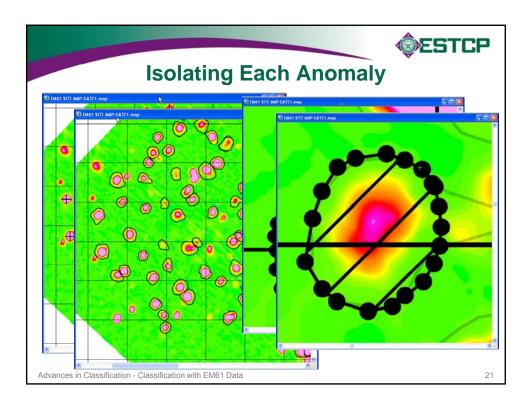


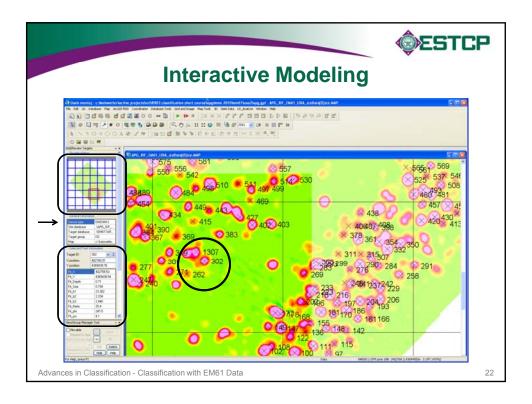


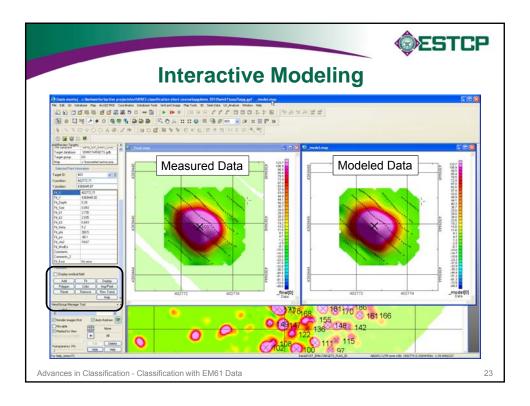


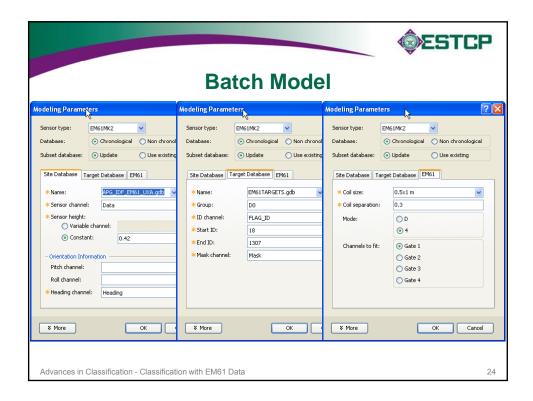


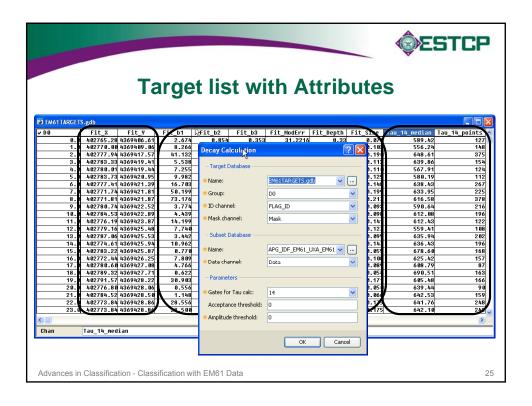


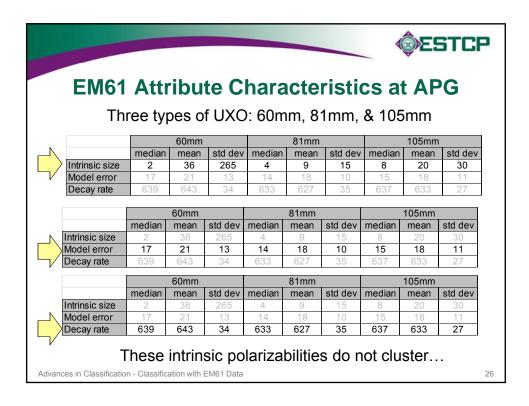


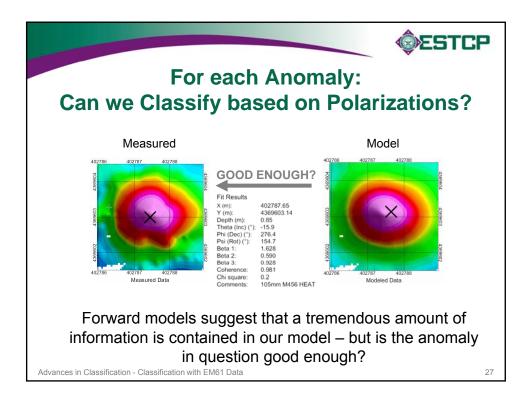


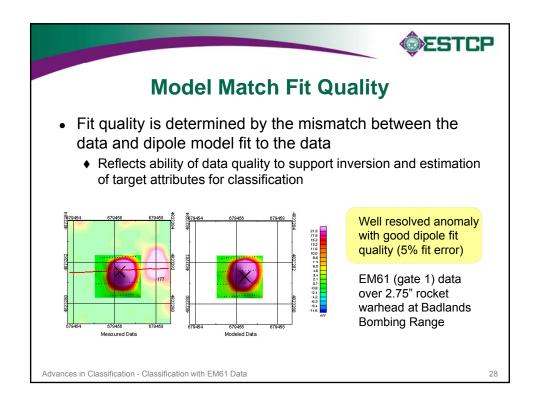


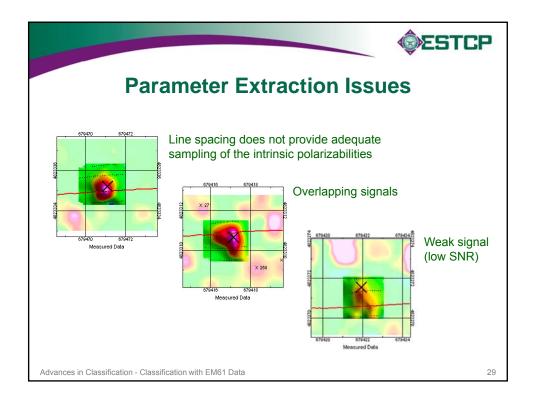


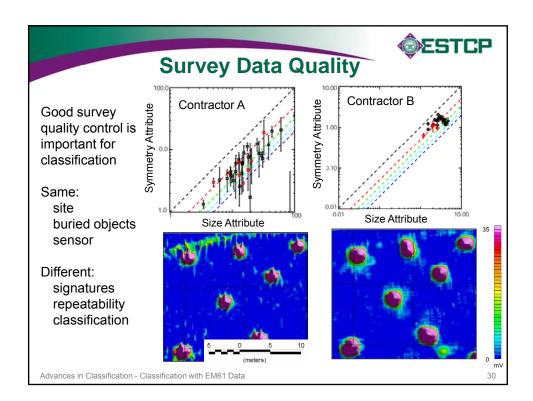


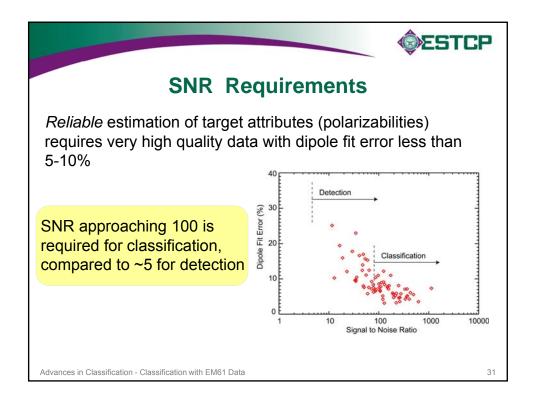


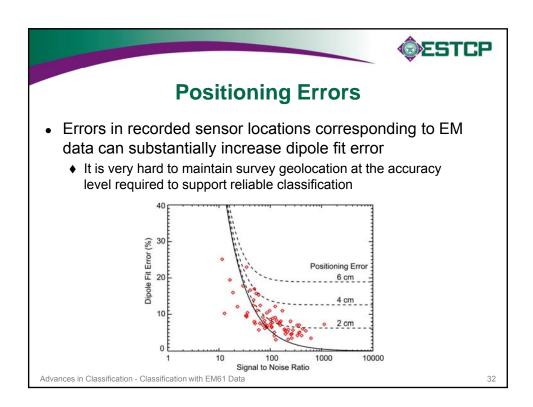












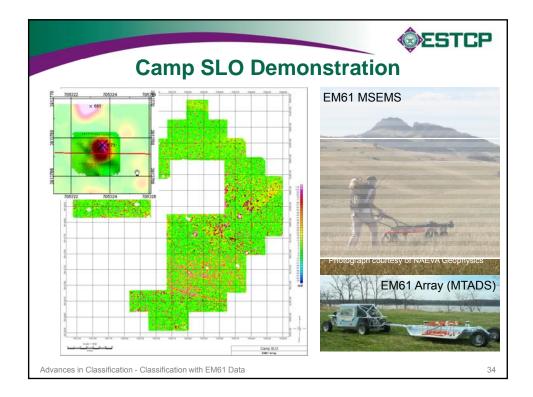


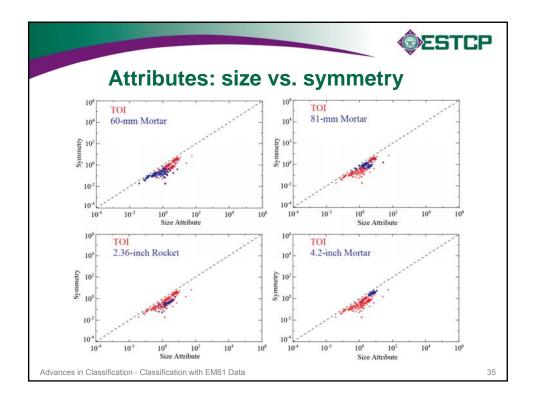
# **Data Requirement Summary**

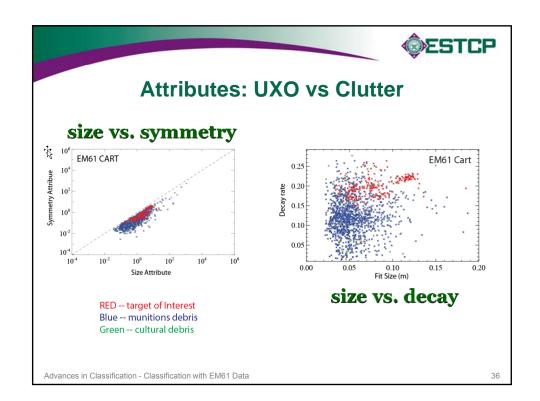
- · Inversion requires accurately mapped survey data
  - ♦ Also requires sensor orientation and vertical position
- Data density and spatial extent must adequately sample the principal axis polarizabilities
- No overlapping signals
- SNR needed for classification > SNR needed to detect object

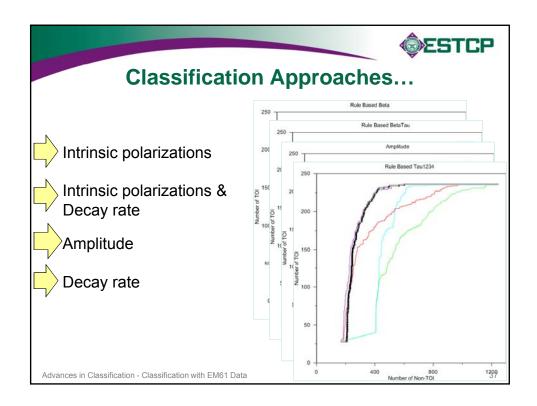
Advances in Classification - Classification with EM61 Data

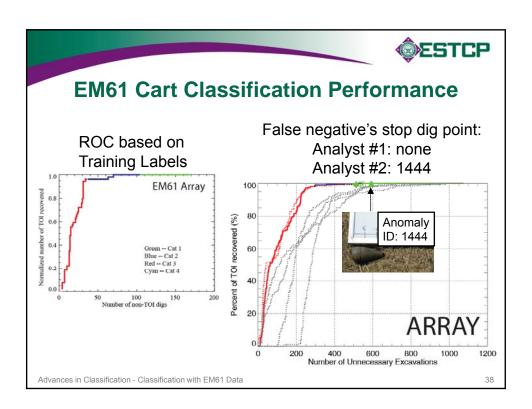
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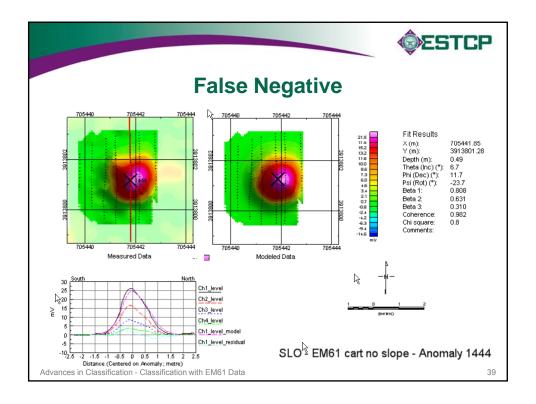


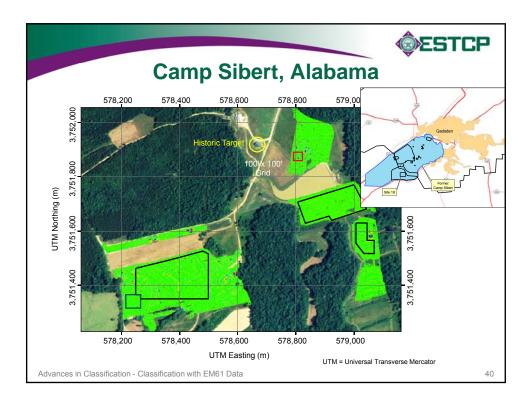


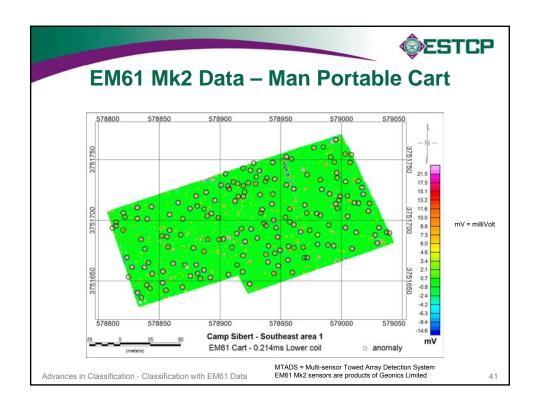




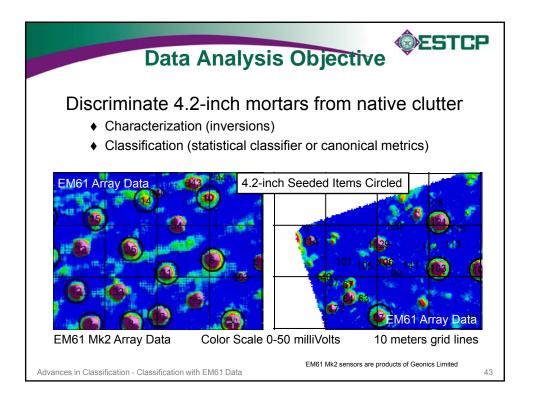


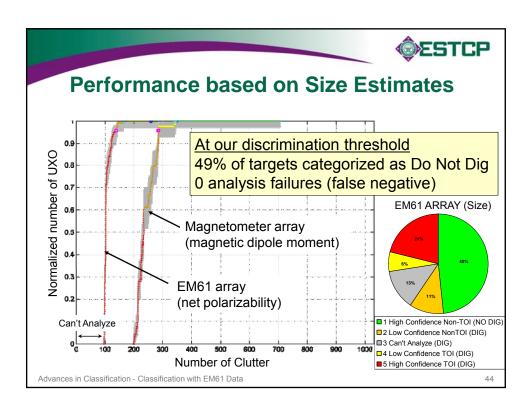


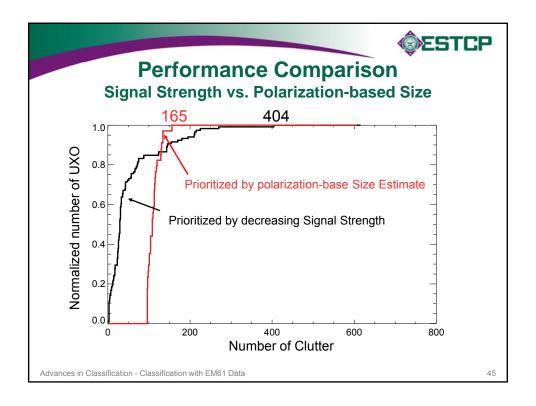














### **Summary**

Respectable classification results can be realized using EM61 data for some sites

Target size and decay rate were the best attributes for the Camp Sibert and Camp San Luis Obispo demonstrations

Classification performance is typically poor if target shape estimates are required from survey mode EM61 data

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### **Module Outline**

- Limitations of conventional sensor technology
  - Basic design considerations for advanced sensors
- Advanced sensor systems
- Performance
  - Principal axis polarizabilities
  - Classification performance

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### The Classification Problem

- Classification performance using conventional EMI sensor technology is limited by two primary factors
  - The eddy current decay cycle is not fully captured
  - Multi-cm positioning errors inherent to field survey work compromise the accuracy of dipole inversion and estimation of target attributes
- New UXO-specific technologies which avoid these problems are being developed and tested under SERDP and ESTCP

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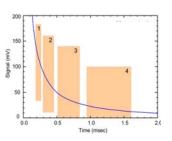
# **ESTCP**

### **Conventional Sensor Technology**

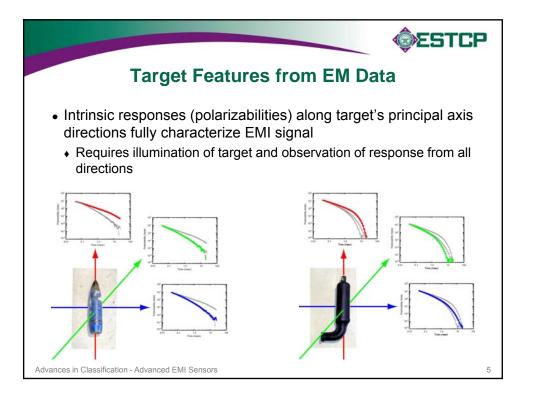
### Geonics EM61 Mk2

- Industry standard for geophysical surveys in munitions response
  - Eddy current decay signal over four time gates centered at 216, 366, 660, and 1266 μsec
- Best UXO detection performance at 1994-96 Jefferson Proving Ground technology demonstrations
- Efforts to process survey data for shape-based target classification largely unsuccessful





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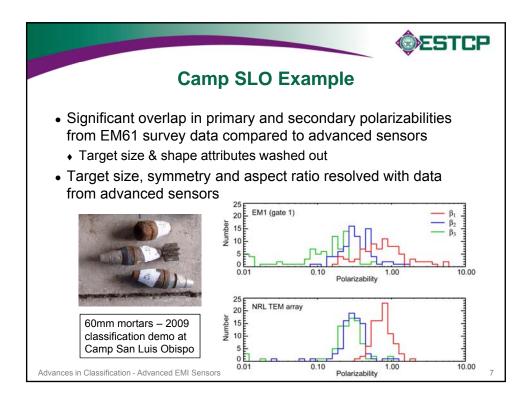


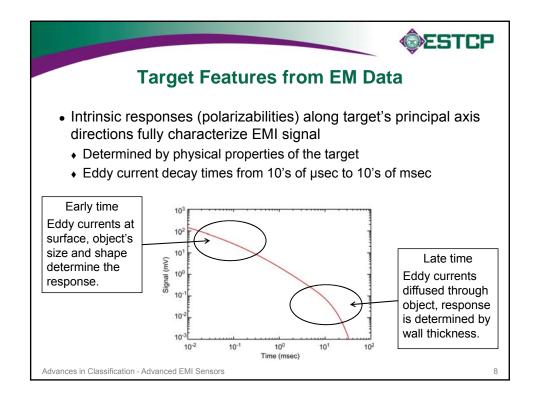
### **Target Features from EM Data**

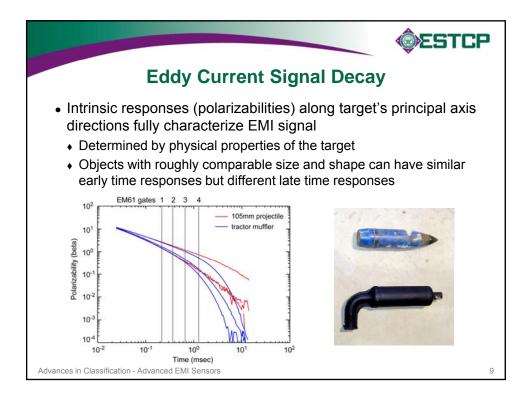
- Intrinsic responses (polarizabilities) along target's principal axis directions fully characterize EMI signal
  - Requires illumination of target and observation of response from all directions
  - Cannot be accurately determined from conventional survey quality EM data because of positioning uncertainty
  - Advanced sensors use fixed coil arrays for precise positioning of sensor readings to allow accurate calculation of principal axis polarizabilities

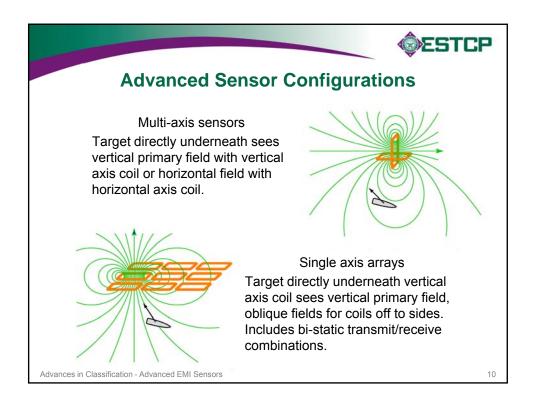
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### **Survey vs. Cued ID Operation**

- Classification using survey data from moving sensor arrays is challenging
  - Exciting target from different directions and observing response to late times takes time
  - · Data density along survey lines suffers
- Most current systems use cued identification approach
  - Park sensor over previously flagged anomaly, collect data and move on to next anomaly
  - Several hundred targets per day possible

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# **Advanced Sensor Systems**

- Multi-axis sensor systems
  - BUD Berkeley UXO Discriminator (Lawrence Berkeley Nat'l Lab)
  - MetalMapper (Geometrics, G&G Sciences, Snyder Geoscience)
  - ALLTEM (US Geological Survey)
  - ◆ EM63-3D Mk2 (Geonics)
- Single axis arrays
  - ◆ TEMTADS Transient EM Towed Array Discrimination System (US Naval Research Lab, Nova Research, G&G Sciences, SAIC)
- Man-portable and handheld derivatives
  - Handheld BUD
  - Man-portable vector sensor (G&G, ERDC Hanover, Sky Research)
  - Man-portable and handheld TEMTADS

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# **Berkeley UXO Discriminator (BUD)**

- 3 orthogonal transmit coils (1 m square) 8 receive coil pairs
  - 24 independent Tx/Rx measurements of transient response from 140 to 1400 μsec
- Survey mode (detection) or cued ID



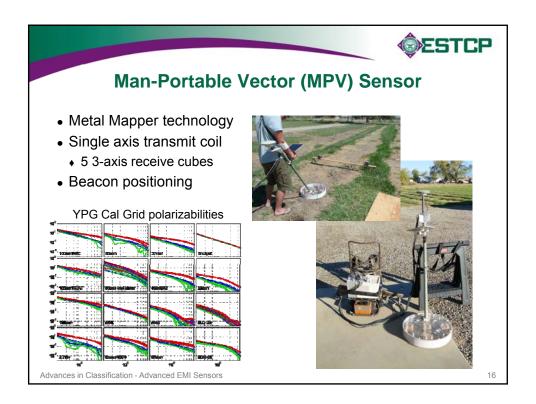


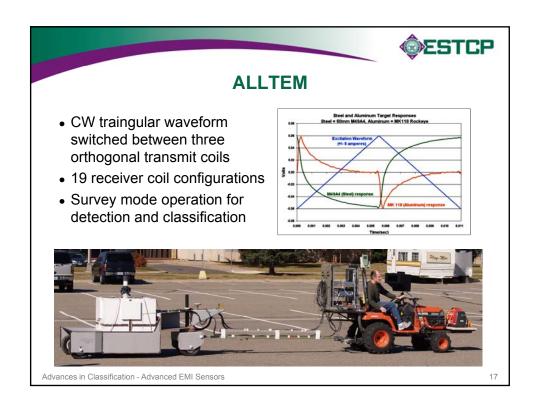
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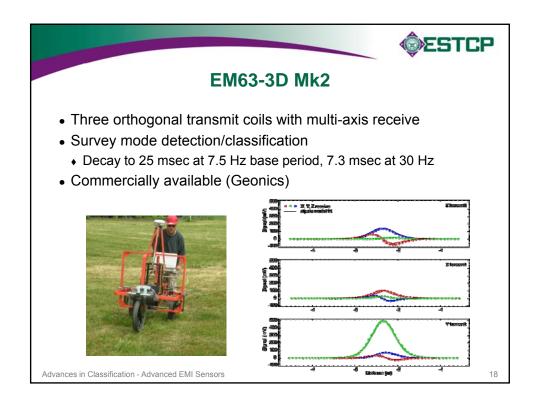
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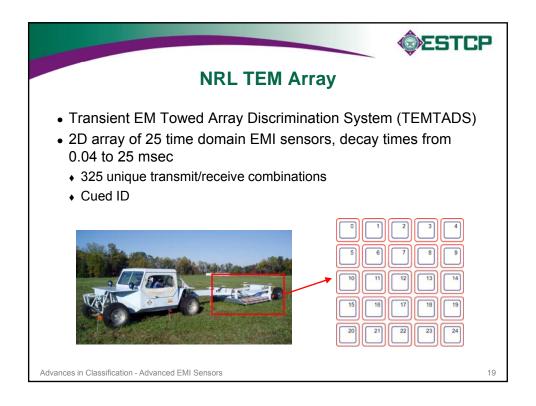
# Handheld BUD • 3-axis transmit coils (30 cm square) – 10 receive coil pairs • Backpack electronics Advances in Classification - Advanced EMI Sensors





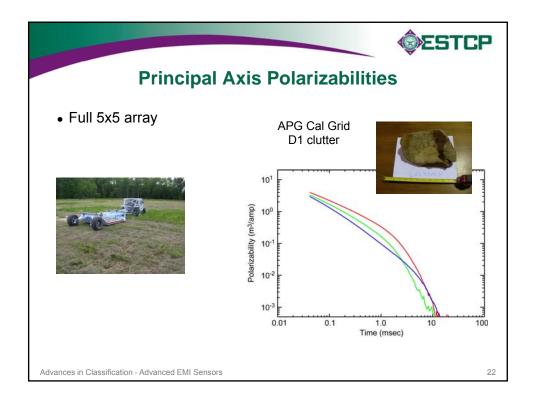


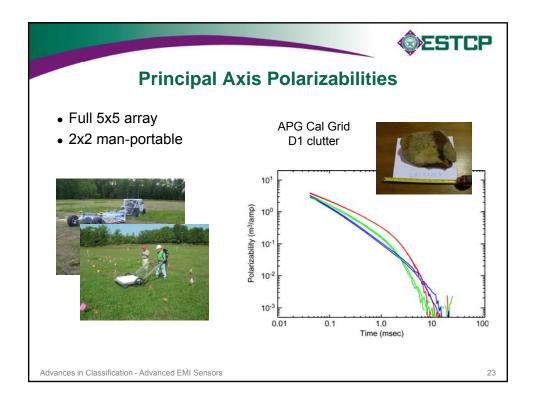


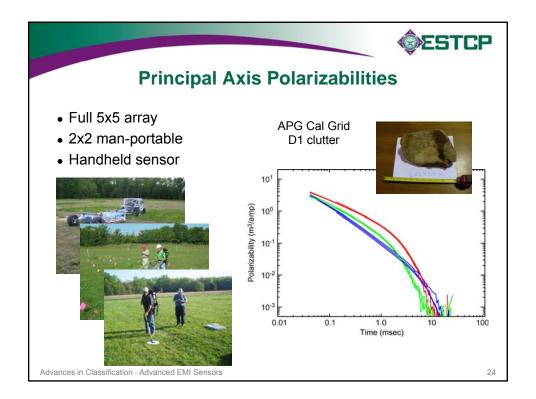


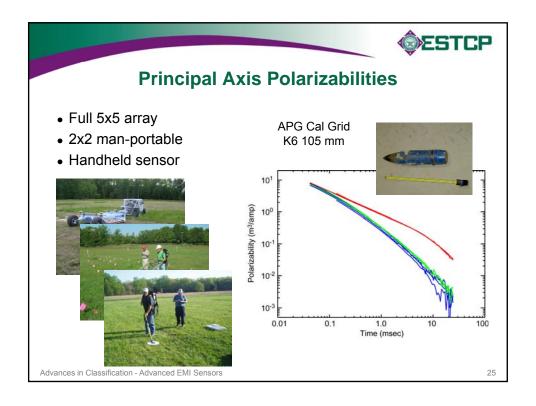


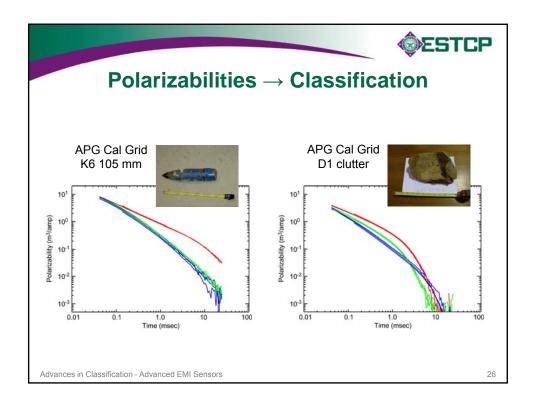


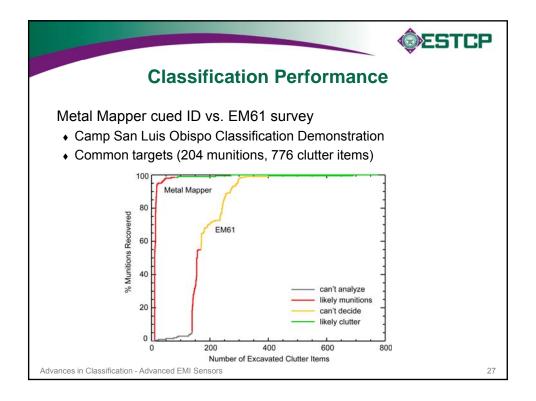












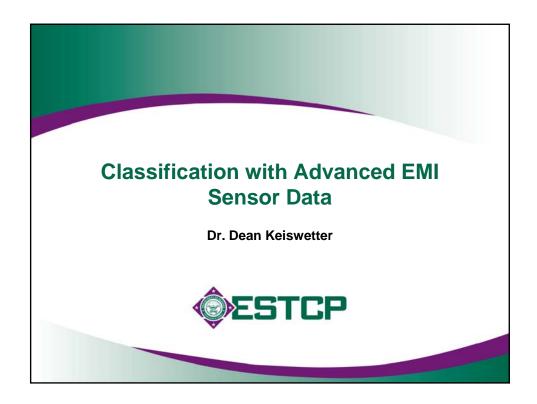


### **Summary**

- Classification performance using conventional EMI sensor technology is limited by two primary factors
  - The eddy current decay cycle is not fully captured
  - Multi-cm positioning errors inherent to field survey work compromise the accuracy of dipole inversion and estimation of target attributes
- New UXO-specific technologies which avoid these problems are being developed and tested under SERDP and ESTCP
  - Results from technology demonstrations are very encouraging
    - Aberdeen & Yuma Proving Ground Standardized Test Sites
    - Former Camp Sibert, Camp San Luis Obispo, Camp Butner live site classification demonstrations

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# **ESTCP**

### **Outline**

- Review
- Data analysis environment / processing overview
- Classification
  - ♦ Approach and features
  - ♦ Aberdeen Proving Ground
  - ♦ San Luis Obispo
- Multiple source situations
- Closing comments

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# Review: Factors Affecting Classification Performance with EM61 data

- Limited capability for target classification in survey mode
  - ♦ Analog smoothing distorts signal shape
  - ♦ Limited decay time coverage
  - Centimeter-level sensor positioning uncertainty degrades target parameter estimates
- Towed arrays have limited target illumination with transmitters operated simultaneously

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## Review: EMI Sensors designed for Classification

In order to observe the complete EM response pattern the object must be excited and measured from all directions

The new EMI technologies accomplish this with multi-axis coil sensors or single axis coil arrays



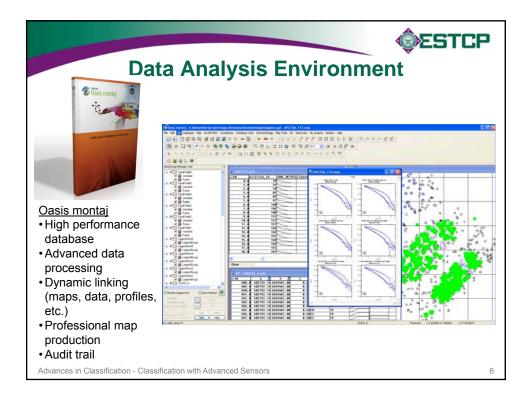


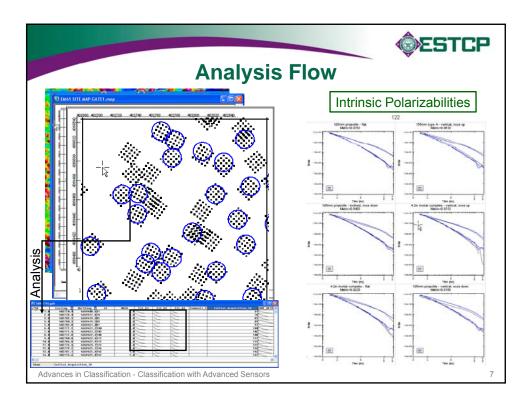
Multi-axis coil array

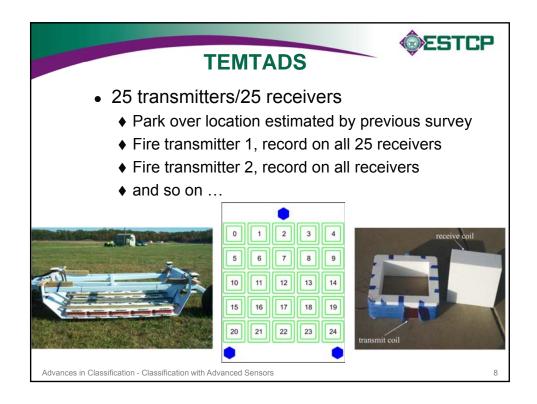
Single axis planar array

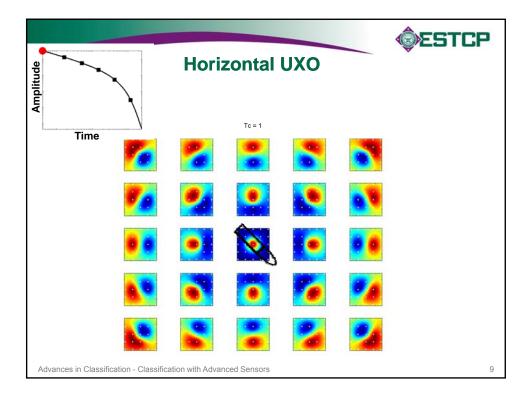
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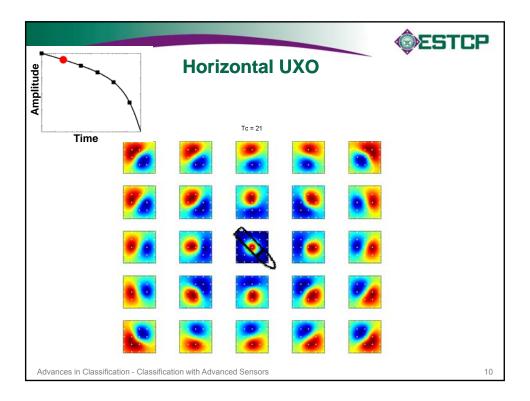


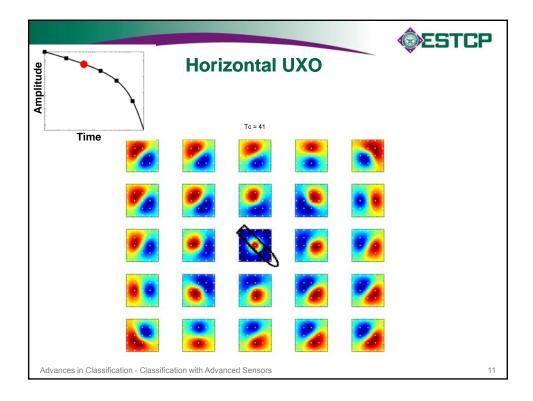


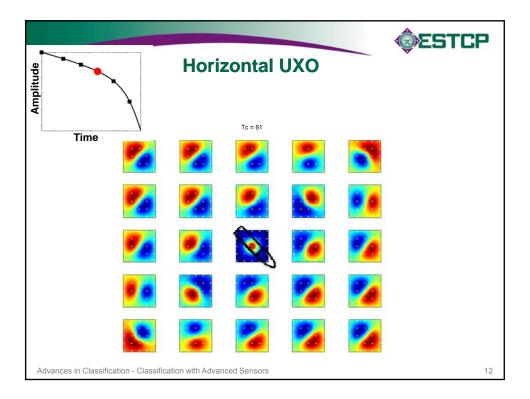


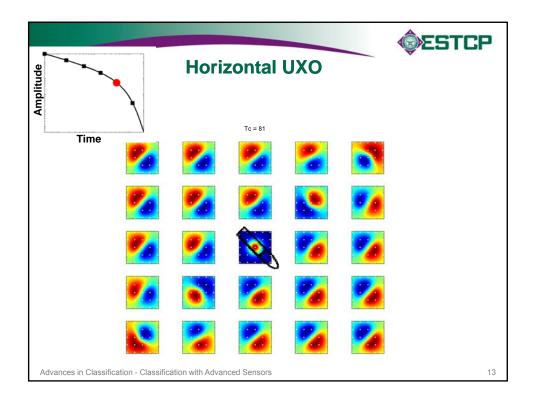


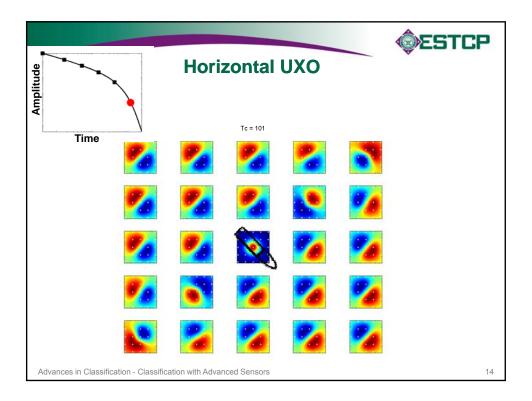


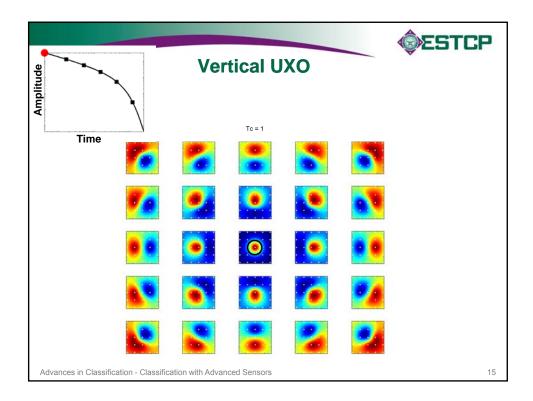


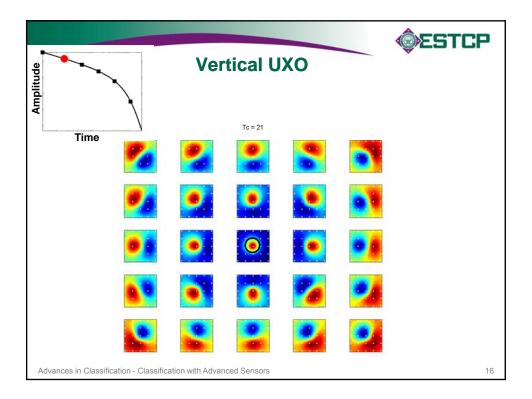


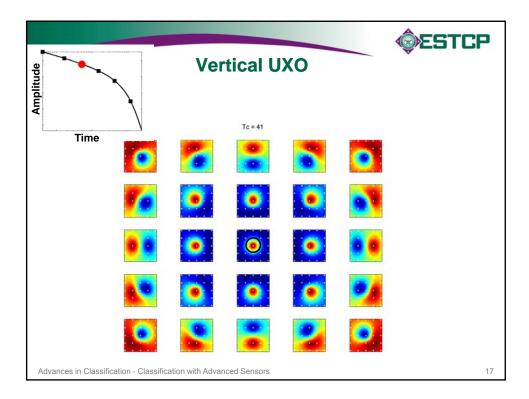


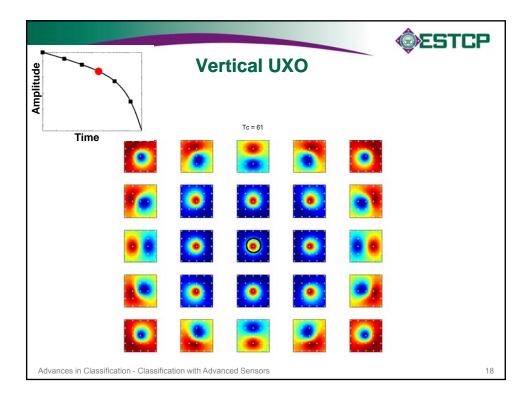


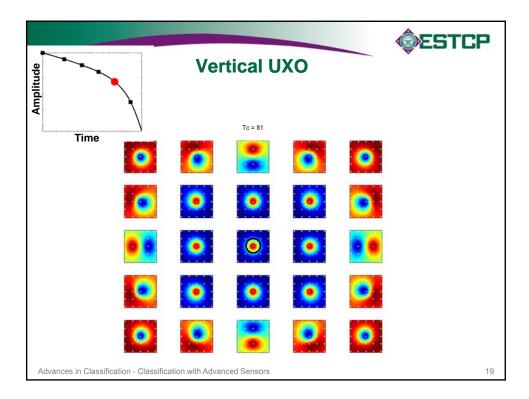


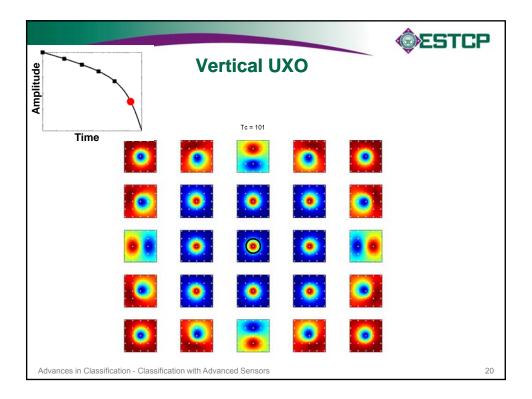


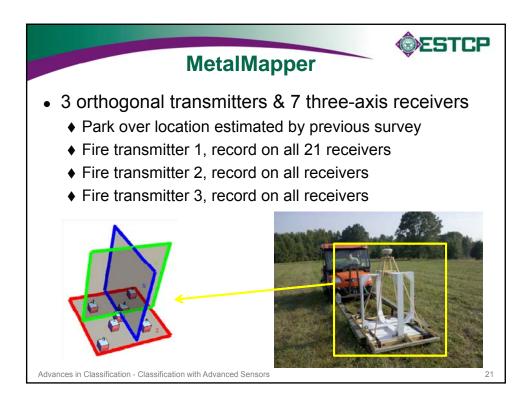


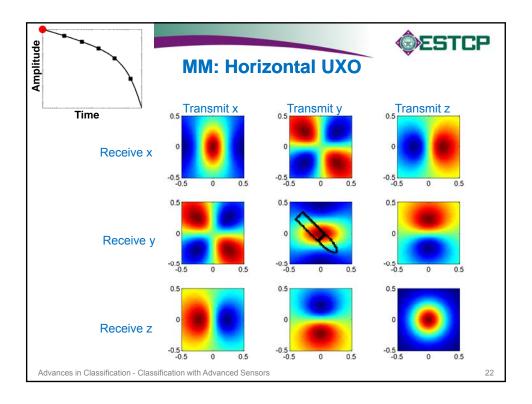


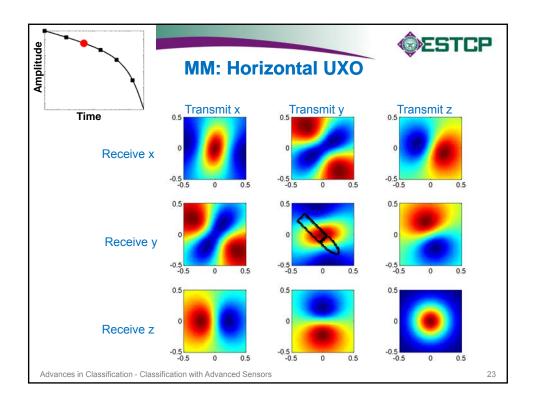


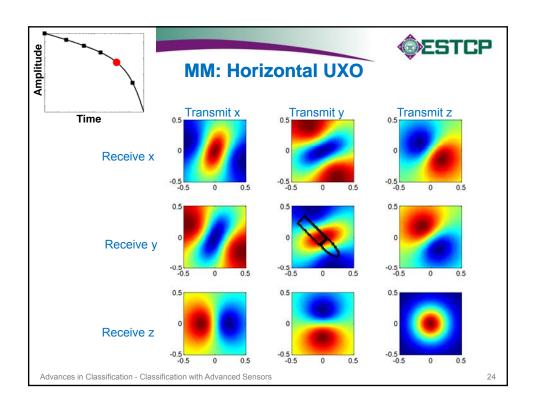


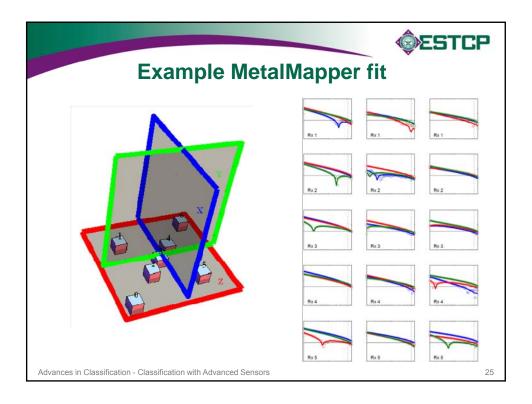


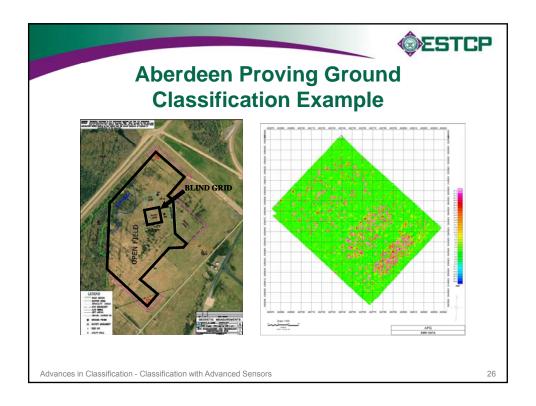


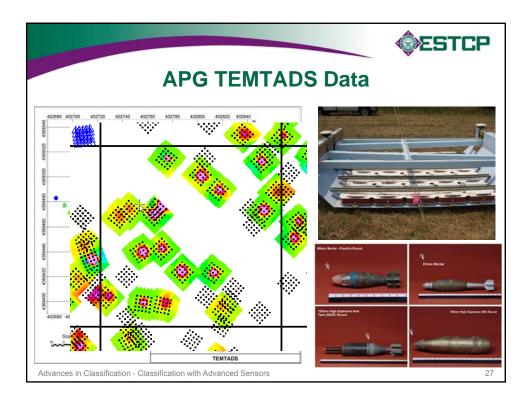


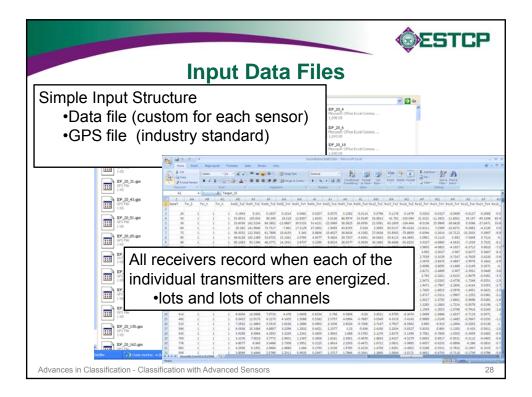


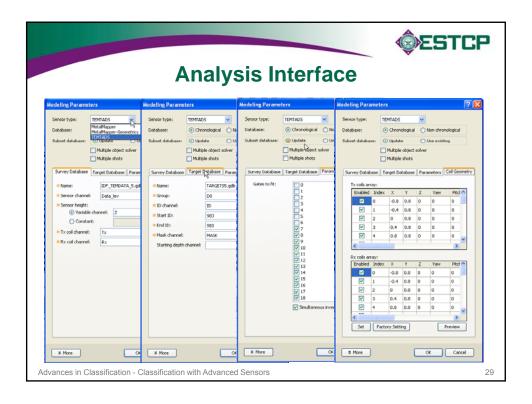


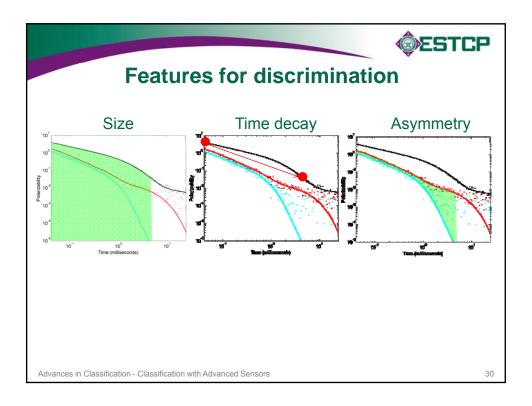


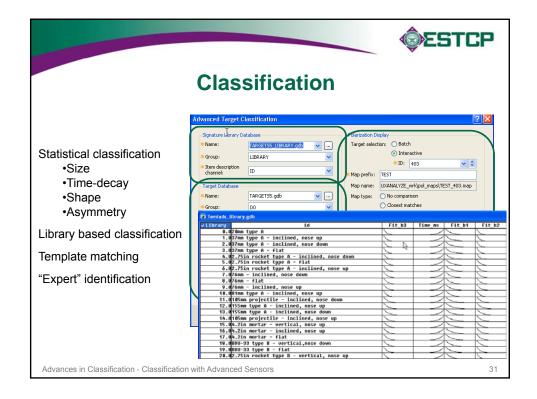


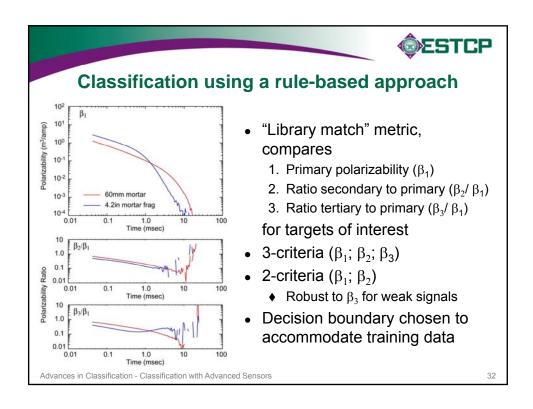


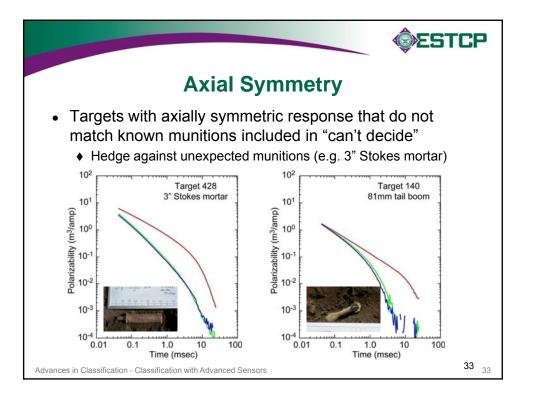














## Can't Analyze & Can't Decide

#### Can't Analyze

Lack of data due to a sensor-specific data gap Inversion fails to converge Inversion produces unphysical parameters (depths >2m or

negative polarizabilities)

#### Can't Decide

Low SNR

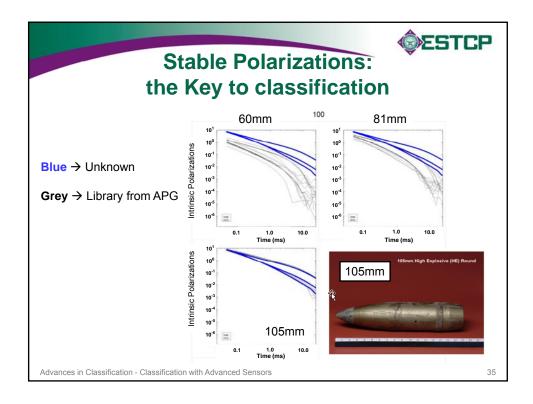
Multiple sources suspected (overlapping signatures) Axially symmetric\* (but does not match library) Buffer zone\*

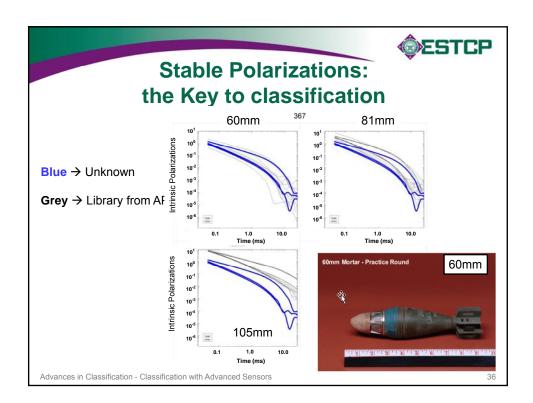
\*TEMTADS & MetalMapper

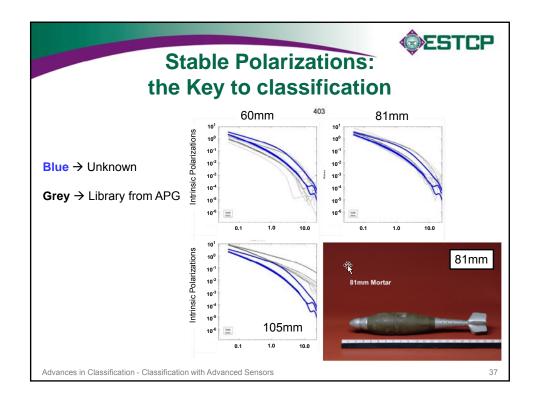
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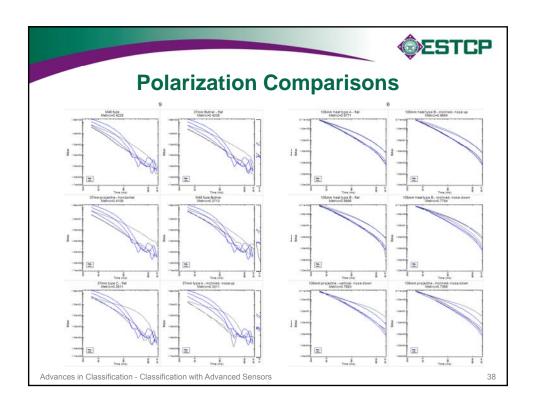
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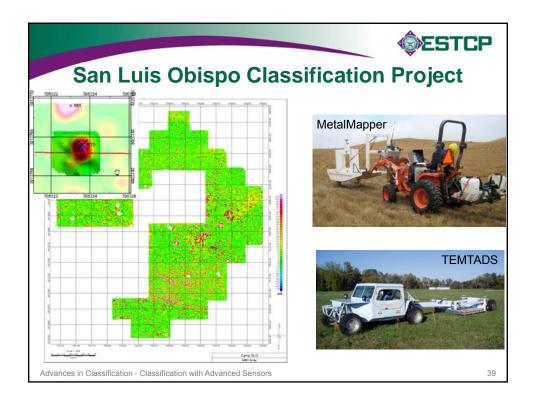
December 1, 2010 17

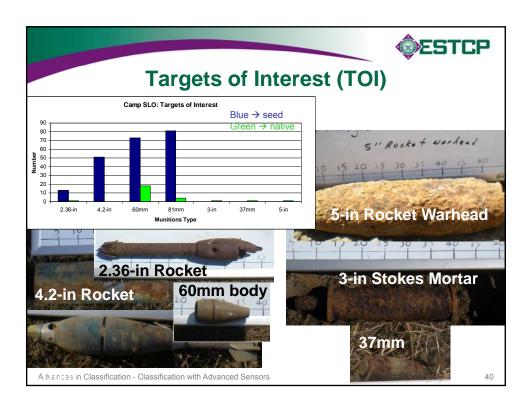




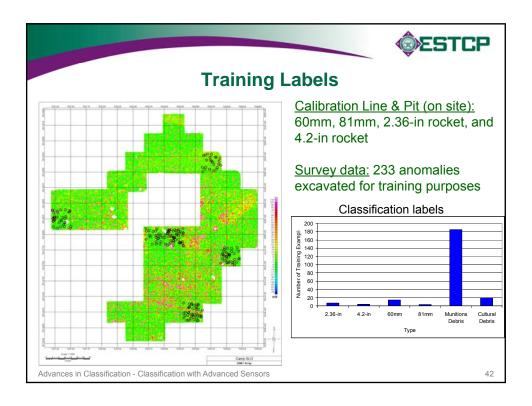


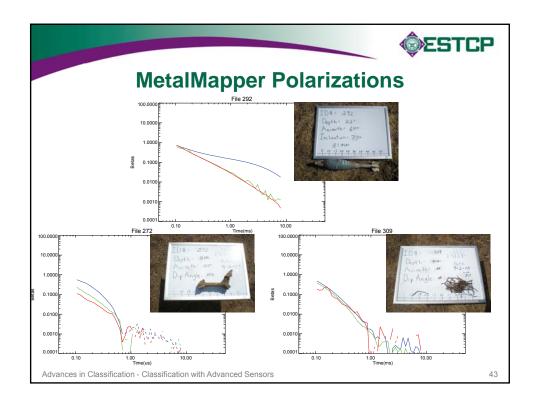


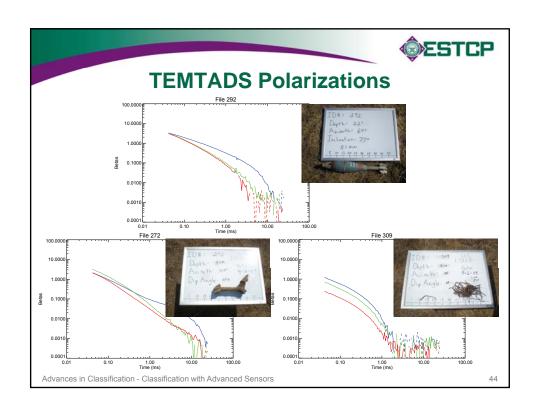


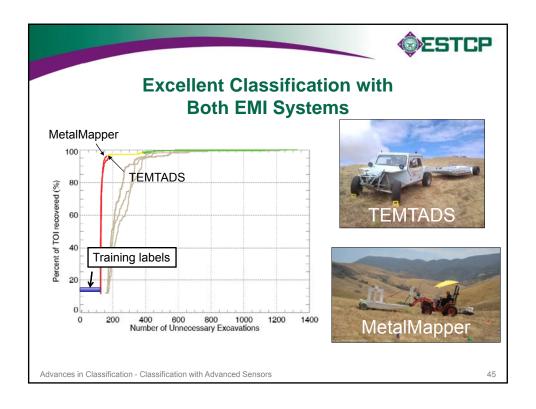


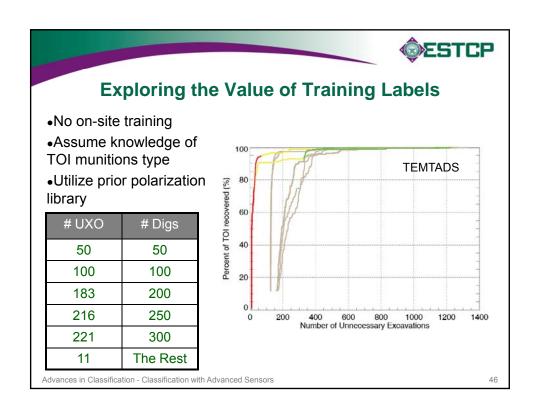


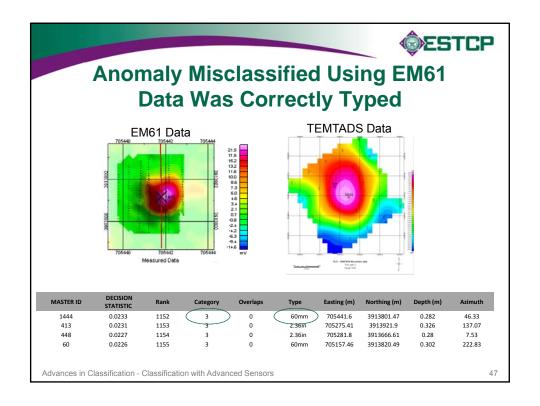


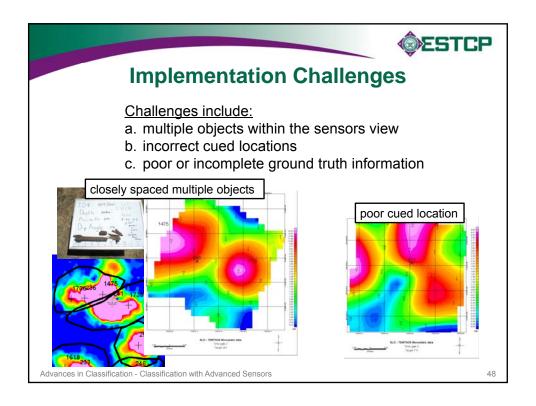














## **Non-Inversion Approaches**

Non-traditional approaches are being pursued by a number of research firms.

#### Objective(s) include:

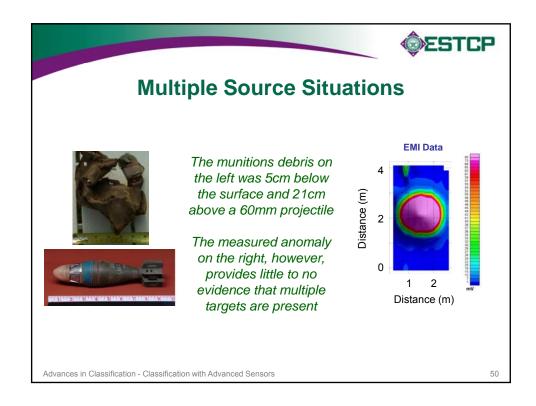
- · Detect and classify using survey data
- Increase speed of calculations
- · Decrease noise sensitivity
- Require fewer measurement systems (such as geolocation)
- · Reduce data demands

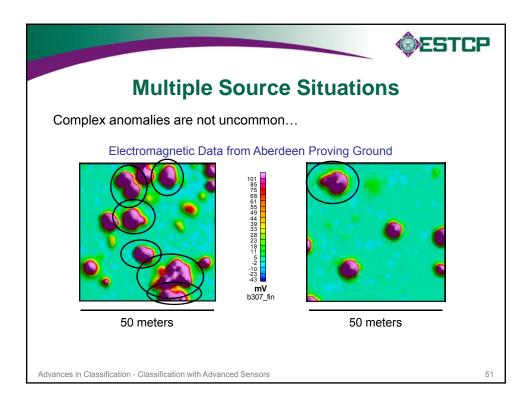
Key: Intelligent use of the output from multi-axis loop sensors

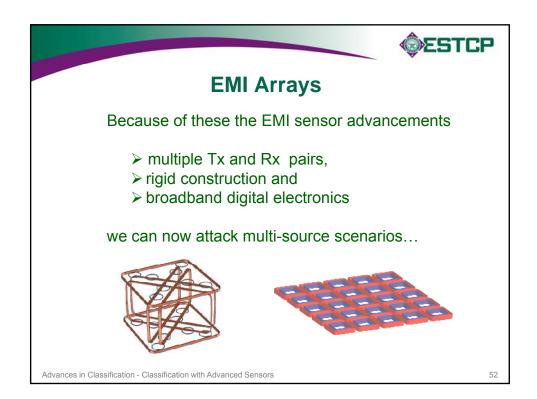


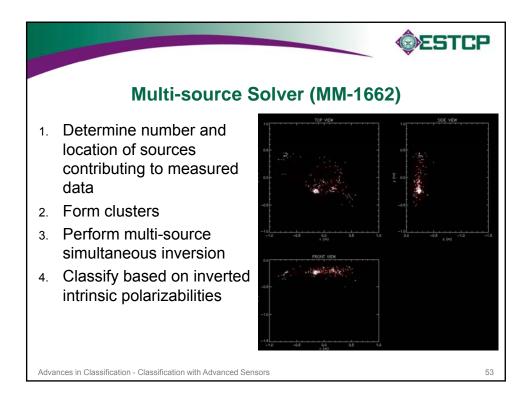
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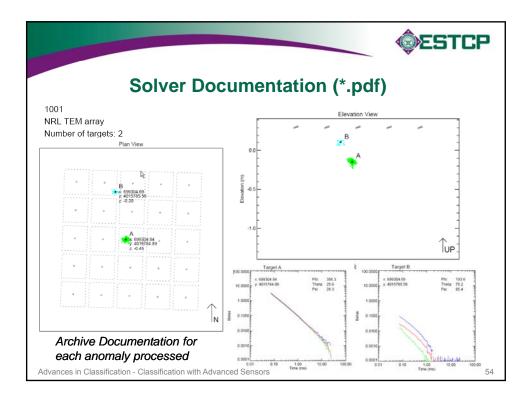
19

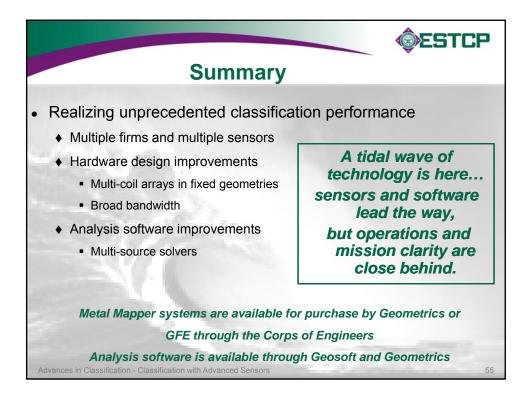


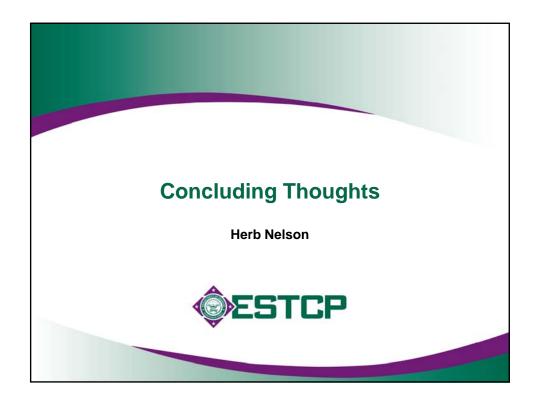














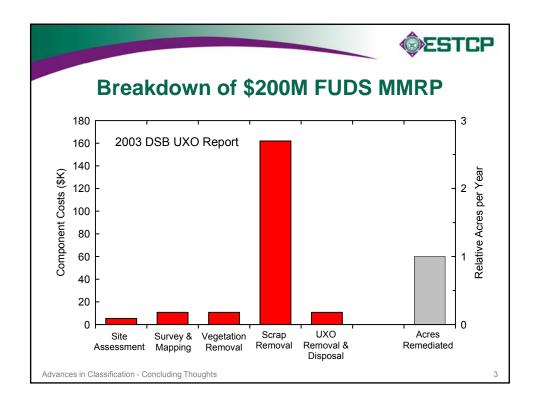
## **Objective of the Course**

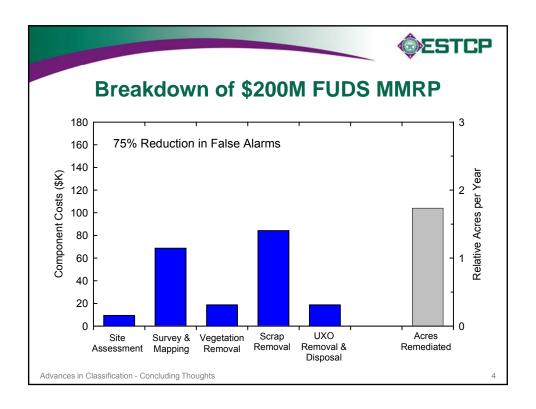
Provide an update on the sensors, methods, and status of the classification of military munitions using geophysical methods

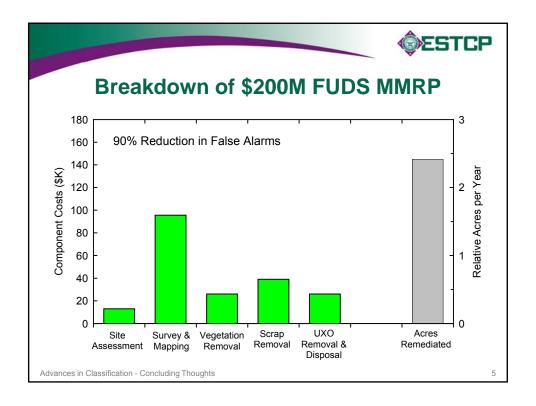
- Advanced processing of data collected with existing commercial instruments
- Significant improvements possible using advanced EMI sensors

Advances in Classification - Concluding Thoughts

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## **Implementation Approaches**

- · Hazard-based dig decision
  - ♦ High confidence non-hazardous anomalies remain in the ground
  - ♦ Remaining anomalies are dug
- Hazard-based dig protocol
  - ♦ High confidence non-hazardous anomalies dug with one UXO tech supervising a team of lower-cost diggers
  - Remaining anomalies are dug with usual procedures (UXO personnel and safety equipment)

Approach would be site dependant and determined by the site team

Advances in Classification - Concluding Thoughts



## **Acceptance**

- Requires transparent process involving explicit, documented classification
- Continued collaboration with stakeholders- Advisory Group and beyond
- Need to start thinking about things like QC methods

Advances in Classification - Concluding Thoughts

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## **Joint Web Site**



Meeting DoD's Environmental Challenges

- SERDP & ESTCP Information at One Location
  - ♦ Easy access to all information
    - Funding opportunities
    - Investigator resources
    - Research results
  - ♦ Highlights program areas and initiatives
  - ♦ Platform for technology transfer: Tools and Training

serdp-estcp.org

Advances in Classification - Concluding Thoughts

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